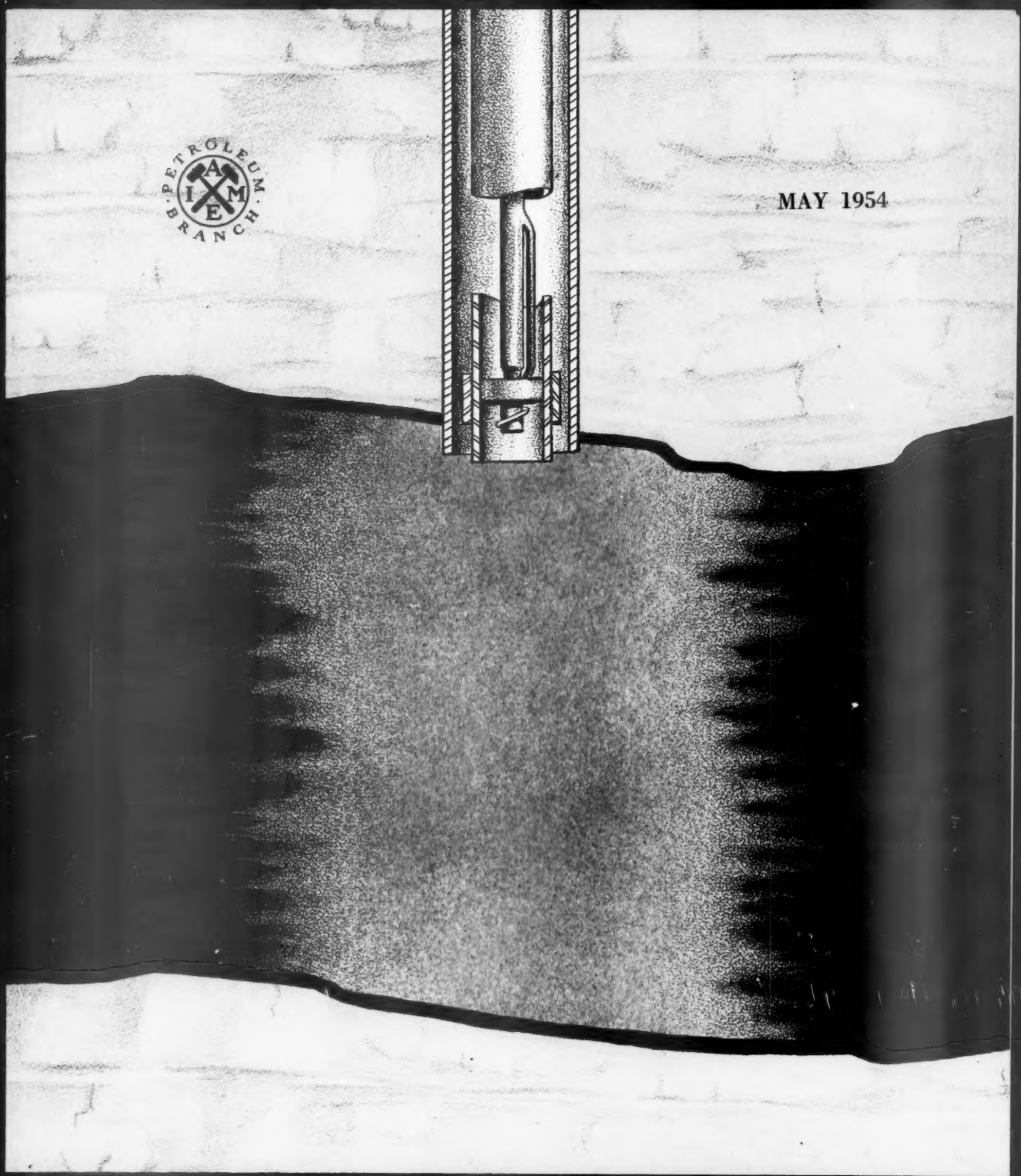


MAY 1954

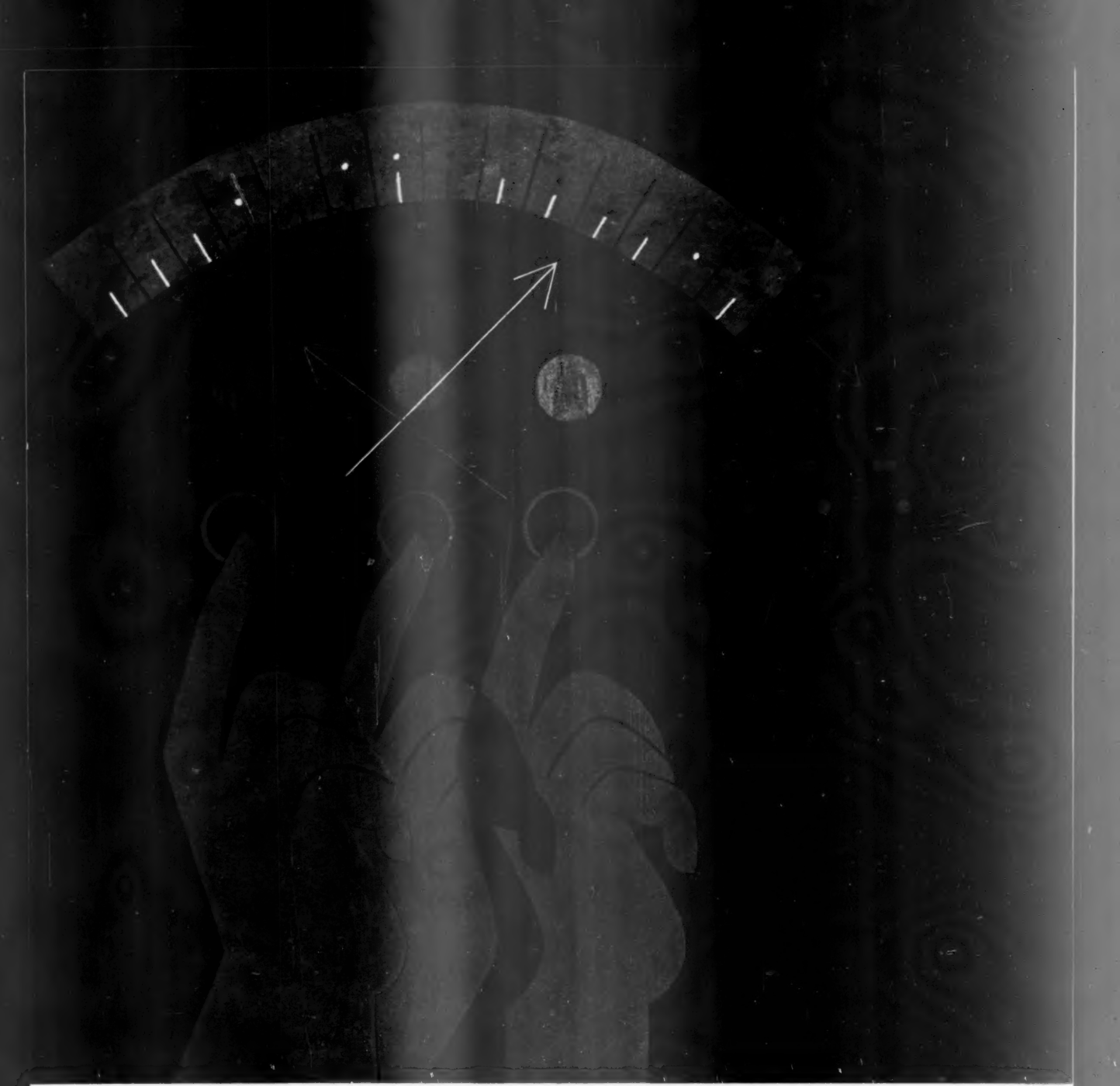
JOURNAL OF PETROLEUM TECHNOLOGY

OIL MEANS INDUSTRIAL DEVELOPMENT

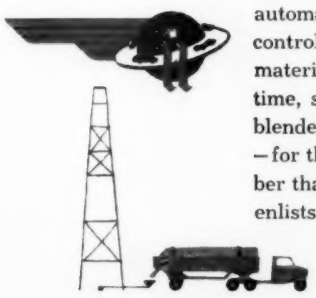
New manufacturing processes . . . new products . . . have come from the development of new uses for oil and its by-products. In the daily job of finding additional oil resources, the Schlumberger Electrical Log . . . the pioneer well logging service . . . has long been recognized as the most important single subsurface exploration method available to the industry.

. . . and Schlumberger means Service

Schlumberger Well Surveying Corp. • Houston, Texas



CEMENTING *is the control of cements*



The cybernetic age, we're told, is already here. In simplest form it means that operations are automatically controlled by electronics. One way that Halliburton uses cybernetic principles is in control of batch mixing materials at its bulk cement stations throughout the country. Cement materials for each well are specially selected to combine properties of thickening time, setting time, strength, corrosion resistance, perforating qualities, etc. Correct proportions, thoroughly blended, are of major importance—accuracy in weighing and measuring is extremely necessary—for the control of cements is what makes cementing effective. Next time you're W.O.C. remember that Halliburton, in addition to its two-million-job experience and quarter-century research, enlists the aid of cybernetics to keep cementing under control.

"THERE'S NO SUBSTITUTE FOR EXPERIENCE IN OIL WELL CEMENTING"

HALLIBURTON OIL WELL CEMENTING COMPANY
DUNCAN, OKLAHOMA

VISCO
REG. U.S. PAT. OFF.
OIL TREATING
507
COMPOUND
55 U. S. GALLONS
VISCO PRODUCTS CO. Inc.
HOUSTON, TEXAS

READY WILLING AND ABLE

to unload your well in the QUICKEST TIME

THE GUIBERSON "J" TUBING SWAB CUP

Any load you can safely handle will come up with the "J"—the tough, heavy-duty cup that's designed to bring out everything but the tubing! Extremely durable, fast falling. No down-swabbing, no hanging on collars. Long, strong flexible lip for perfect up-stroke seal.

"L" Cup for medium and light loads.

"K" Cup for light loads in medium and shallow wells.

"GW" Cup for last-cupful unloading of shallow wells.

The Guiberson "J" Cup will bring up anything you want to lift! Look for it in the Yellow Box!

SAFE THAN SORRY — BETTER BE — GUIBERSON

GUIBERSON

CORPORATION

DALLAS, TEXAS, U. S. A.

Sold By Leading Oil Field Supply Stores Everywhere

Better Be Safe Than Sorry!

EXPERIENCE

A MEASURE OF QUALITY

The name "Core Lab" is synomymous with "Experience." Eighteen years' work in all active areas, under all types of formation productive tendencies, contributes greatly to the broad acceptance of Core Lab data by operators, purchasers of reserves, and state regulatory boards. The factual and interpretive qualities of Core Lab's Core Analysis Reports are measured by the experience of performing 25,000 individual core analyses and 700 different reservoir fluid analyses. Sooner or later you'll be faced with the question, "pay-out or play out"? Let Core Lab's experience establish your answer *now*.

DALLAS, HOUSTON, CORPUS CHRISTI, MIDLAND, ABILENE, SAN ANTONIO, TYLER, TULSA, FT. WORTH, WICHITA FALLS, OKLAHOMA CITY, ARDMORE, PAMPA, ARKANSAS CITY, GREAT BEND, NEW ORLEANS, SHREVEPORT, HATTIESBURG, JACKSON, LAFAYETTE, DENVER, BAKERSFIELD, WORLAND, STERLING, BILLINGS, CASPER, EL DORADO, LUBBOCK, FARMINGTON, LOVINGTON, CALGARY, EDMONTON, REGINA, CANADA; VENEZUELA, S. A.

JOURNAL OF PETROLEUM TECHNOLOGY

MAY, 1954

OFFICERS • COMMITTEES

Chairman: John R. McMillan
Fullerton Oil Co., Pasadena, Calif.

Vice-Chairmen:
Thomas C. Frick
The Atlantic Refining Co., Corpus Christi, Tex.
D. W. Akins
Ohio Oil Co., Shreveport, La.

EXECUTIVE COMMITTEE:
Burton Atkinson
Pishney & Atkinson, Fort Worth, Tex.
Thomas A. Atkinson
Socony-Vacuum Oil Co. Casper, Wyo.
Roland Gouldy
Hull-Silk Repressuring Assoc., Wichita Falls, Tex.
Claude R. Hocott
Humble Oil & Refining Co., Houston, Tex.
W. D. Owsley
Halliburton Oil Well Cementing Co., Duncan, Okla.
E. N. Van Duzee
Shell Oil Co., New York, N. Y.
G. L. Yates
Amstutz & Yates, Wichita, Kan.
Charles R. Dodson
National City Bank, New York, N. Y.
Representing M.I.E.D.
Paul R. Schultz
Stanolind Oil & Gas Co., Tulsa, Okla.
Representing M.E.D.

Treasurer: T. A. Pollard
Magnolia Petroleum Co., Dallas, Tex.
Counsel: Robert E. Hardwicke
Hardwicke, Haddaway & Pope, Fort Worth, Tex.
Executive Secretary: Joe B. Alford
AIME, Dallas, Tex.

COMMITTEE CHAIRMEN:
Admissions: F. G. Prutzman
Sun Oil Co., Dallas, Tex.
Advertising: Thomas C. Frick
The Atlantic Refining Co., Corpus Christi, Tex.
Education: Jack Turner
Phillips Petroleum Co., Bartlesville, Okla.
General Editorial Committee: Glenn M. Stearns
British-American Oil Producing Co., Dallas, Tex.
Membership: Gene L. Scheirman
Shell Oil Co., Kilgore, Tex.
Nominating: Claude R. Hocott
Humble Oil and Refining Co., Houston, Tex.
Transactions Editorial: H. B. Renfro
Petroleum Consultant, Dallas, Tex.
Student Activities: Paul Andrews
Signal Oil & Gas Co., Los Angeles, Calif.
Production Review: R. B. Gilmore, *Chairman*
DeGolyer & MacNaughton, Dallas, Texas
Milton Williams, *Domestic*
Humble Oil & Refining Co., Houston, Tex.
A. H. Chapman, *Foreign*
Arabian American Oil Co., Washington, D. C.
Technology: William L. Horner, *Chairman*
Core Laboratories, Inc., Dallas, Texas
Preston E. Chaney, *Drilling*
Sun Oil Co., Beaumont, Tex.
W. W. Hammond, *Geological Engineering*
Ralph E. Fair, Inc., San Antonio, Tex.
William H. Speaker, *Natural Gas Engineering*
Magnolia Petroleum Co., Dallas, Texas
John H. Thacher, *Petroleum Economics*
California Research Corp., San Francisco, Calif.
Lewis Finch, Jr., *Production Engineering*
Stanolind Oil & Gas Co., Tulsa, Okla.
L. P. Whorton, *Reservoir Engineering*
The Atlantic Refining Co., Dallas, Tex.

OFFICERS OF THE AIME:
President: Leo F. Reinartz
Vice-Presidents: O. B. J. Fraser, J. B. Morrow, Lloyd E. Elkins, A. B. Kinzel, T. B. Counselman, and Harold Decker
President-Elect: H. DeWitt Smith
Past President: Andrew Fletcher
Treasurer and Controller: Gail F. Moulton
Secretary: E. H. Robie

CONTENTS

MAXIMUM LENGTH FOR TECHNICAL PAPERS ESTABLISHED
by H. B. Renfro 9

AN INEXPENSIVE MUD FOR DEEP WELLS
by Henry F. Coffer and Roscoe C. Clark, Jr. 10

DUAL PUMPING WITH FIVE STRINGS OF TUBING
by F. C. Edwards 15

REPORT AND INTERPRETATION
by Joe B. Alford 18

DEVELOPMENT OF AN UNDERGROUND HEAT WAVE FOR OIL RECOVERY
by B. F. Grant and S. E. Szasz 23

A BLOTTER-TYPE ELECTROLYTIC MODEL DETERMINATION OF AREAL SWEEPS IN OIL RECOVERY BY IN-SITU COMBUSTION
by H. J. Ramey, Jr., and G. W. Nabor 35

THE EFFECT OF SURFACE AND INTERFACIAL TENSIONS ON THE RECOVERY OF OIL BY WATERFLOODING
by Harvey T. Kennedy and Erasmo T. Guerrero . . . 41

MEET THE AUTHORS 50

BRANCH AND INSTITUTE AFFAIRS 51

PROPOSED FOR MEMBERSHIP 55

ADVERTISERS' INDEX 58

EDITORS • STAFF

Advisory Editor: Glenn M. Stearns
Editorial Director: Joe B. Alford
Editor: R. W. Taylor
Production Manager: Jan Gartman
Editorial Assistants: Virginia Beilharz, Hattie Hight, Jo Springer
Advertising Manager: Richard C. Wipperman
Eastern Advertising Sales: Lewis V. Hohl, 205 E. 42nd St., New York, N. Y.

Journal of Petroleum Technology is published monthly by the Petroleum Branch, American Institute of Mining and Metallurgical Engineers, Inc., at 800 Fidelity Union Bldg., Dallas 1, Tex. Entered as second class matter at the Post Office at Dallas, Tex. Domestic Subscription: North, South and Central America, $8; foreign, $10; to AIME members, $6 (or $4 if in combination with subscription to either Journal of Metals or Mining Engineering). Single copies, 75 cents; special issues, $1.50. Registered cable address, AIME. Printed in USA. Views expressed herein are not necessarily those of the AIME.

THE AIME ALSO PUBLISHES MINING ENGINEERING AND JOURNAL OF METALS

COPYRIGHT 1954 — AMERICAN INSTITUTE OF MINING & METALLURGICAL ENGINEERS, INC.

The BAKER
RETAINER PRODUCTION PACKER...

What is a Permanent-Type Well Completion?

HERE ARE THE FACTS:

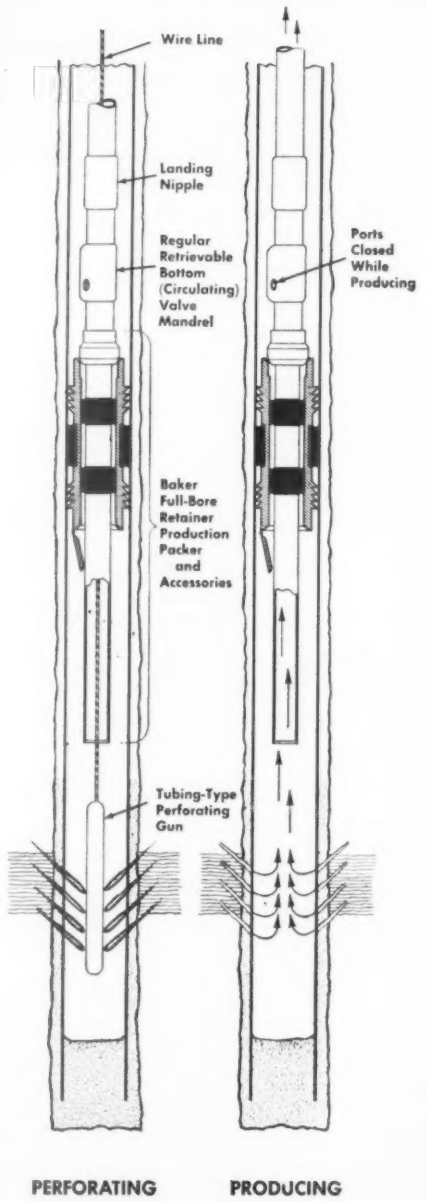
A Permanent-Type Well Completion is generally considered to be an installation providing for completion, production, repair or recompletion in other zones without requiring a drilling or work-over rig.

All tools are run *through the tubing string* after it is landed and nippled up.

If the completion is successful, the tubing need never again be moved until all zones of the selected interval have been exhausted.

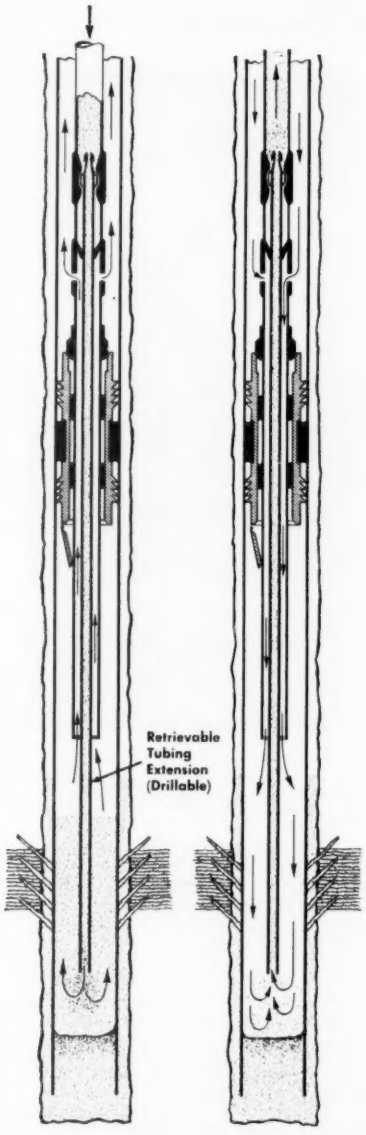
Advantages Claimed for Permanent-Type Well Completions

1. **SAVES AT LEAST ONE TO TWO DAYS RIG TIME during the original completion.**
2. **ELIMINATES COST OF SEPARATE TESTING AND SQUEEZE TOOLS.**
3. **REDUCES WORK-OVER COST AS MUCH AS 75%, by eliminating work-over rig, cost of mud, time and equipment to kill well. Reduces loss of production through saving in work-over time.**
4. **PERMITS THE ECONOMICAL TESTING OF THIN OR QUESTIONABLE SECTIONS.**
5. **PERMITS USE OF WATER INSTEAD OF MUD while perforating completing, or re-completing. This practice reduces formation contamination and may result in an increase in the productivity of the zone.**
6. **PERMITS A MORE ACCURATE ANALYSIS OF RESERVOIR POTENTIAL.**
7. **KEEPS WELL UNDER CONTROL AT ALL TIMES.**



Where PACKERS are required . . . specify a . . .

for Permanent-Type Well Completions



SQUEEZING REVERSING

BAKER PACKERS ADD PERMANENCE TO PERMANENT-TYPE WELL COMPLETIONS

When you select a Packer for a Permanent-Type Well Completion, remember this fact: of all the tools used in permanent-type well completions, only the *Packer* is required to be *permanent.* Guns, Extensions, Plugs, Gas-Lift and Circulating Valves can be removed or replaced on wire line . . . but the Packer, like the casing, is required to perform for the life of the selected producing intervals.

Baker Packer Completions are Permanent Completions from the standpoint of packer performance. Check these important advantages of the Baker Packer in Permanent-Type Well Completions:

Advantages of Baker Retainer Production Packer in Permanent-Type Well Completions:

1. **PERMANENT, RELIABLE PACK-OFF will hold against any pressure differential from above or below that is safe for the casing.**
2. **FREE TUBING STRING . . . neither set-down tubing weight nor tubing tension required to achieve and maintain pack-off. Tubing can be anchored to Packer if desired.**
3. **CAN BE USED AS A SQUEEZE OR A PRODUCTION TOOL.**
4. **MEETS PERMANENT-TYPE WELL COMPLETION DIMENSIONAL REQUIREMENTS.**
5. **CAN BE SET ON WIRE LINE.**
6. **PERMITS EASY REMOVAL OF TUBING STRING.**
7. **READILY DRILLABLE IN CASE OF EMERGENCY OR NEED.**

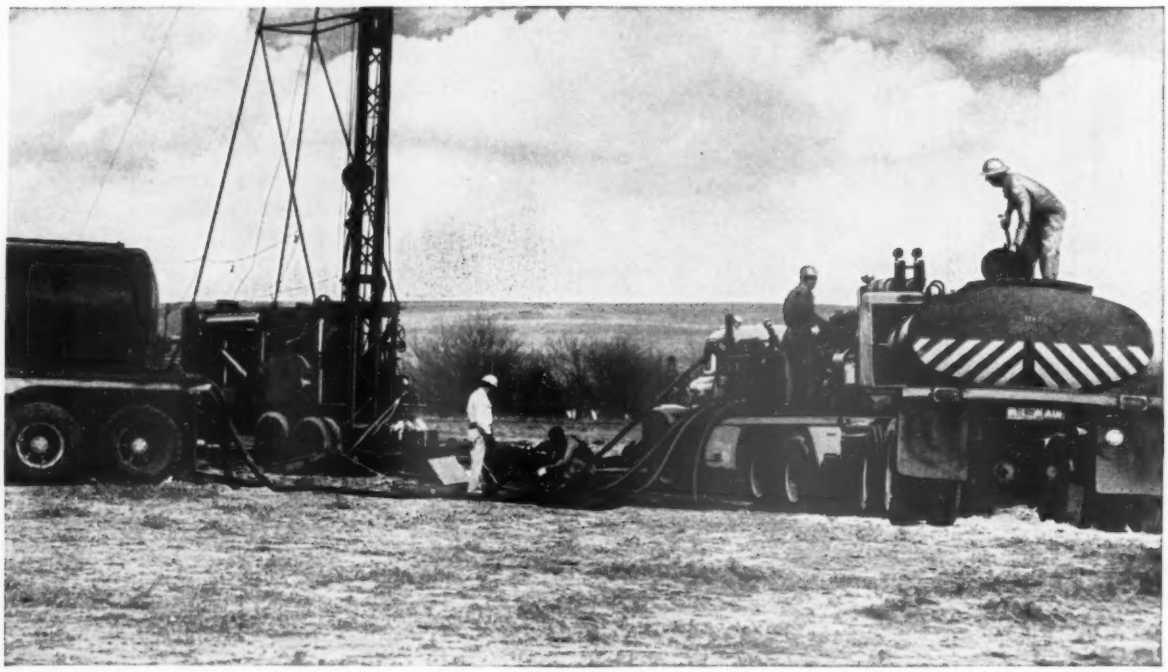
BAKER OIL TOOLS, INC.
HOUSTON • LOS ANGELES • NEW YORK

BAKER

RETAINER PRODUCTION PACKER
PRODUCT NO. 415-D

PRODUCTION INCREASED FROM SHOW TO 336 BOPD WITH SANDFRAC*

Economical fracturing treatment, developed by Dowell, produced profitable results in low-solubility formation



A new well completed in a sand formation gave only a show of oil. The operator decided to use Sandfrac®, a Dowell fracturing service, to make a commercial well. Dowell engineers performed the job, using 1000 gallons of oil and 600 pounds of sand. After treatment, the well made 336 BOPD.

Sandfrac has shown consistent success in both new and old wells —in sandstone, conglomerate and dolomitic formations.

In Sandfrac treatments, special refined oils and selected sands are displaced into the producing formation. The oil returns to the well bore after treatment and the sand remains to act as a propping agent in existing and newly created fractures. Thus, the effective drainage area of the well is increased.

A recent development in fracturing methods is the use of sand in batch treatments—a fine-grained sand followed by a coarse-grained one.** This technique helps eliminate the sand screen-outs which can occur in the treatment of some types of dense, tight pay zones.

Thousands of operators have profited from these additional Sandfrac advantages: (1) Sandfrac can be tailor-made to fit specific well conditions; (2) it is a low-cost fracturing service; (3) no shut-in time is required; (4) no jel-breaker solution is necessary; (5) the oils used can be resold by the operator.

Dowell engineers furnish all materials and especially designed, high-pressure pumping equipment. Their experience on thousands of these jobs helps assure you of dependable service.

For more complete details on Sandfrac and other services developed by Dowell, call the Dowell station or office nearest you; or write directly to Tulsa 1, Dept. E15.

*Sandfrac is a registered service mark of Dowell Incorporated.
**U.S. Patent No. 2,354,570—licensed only to Dowell Incorporated.

DOWELL SERVICE

Acidizing • Fracturing • Electric Pilot • Perfojet
Paraffin Solvents • Bulk Inhibited Acid • Jelflake®
Corban® • Chemical Cleaning for Heat Exchange Equipment

DOWELL INCORPORATED • TULSA 1, OKLAHOMA
A Subsidiary of The Dow Chemical Company

"First in Oilfield Acidizing . . . Since 1932"

Look to
DOWELL
FOR OIL INDUSTRY CHEMICAL SERVICE

EDITORIAL

MAXIMUM LENGTH for TECHNICAL PAPERS ESTABLISHED

H. B. RENFRO

CHAIRMAN
TRANSACTIONS EDITORIAL COMMITTEE

The Transactions Editorial Committee, which selects the papers for publication in this JOURNAL, has found it necessary to establish an arbitrary maximum length for such papers. A maximum of 8,000 words minus 250 words per illustration has been established by the Committee.

There is a limited amount of space available for publication of technical papers. This, combined with an increasing number of papers being submitted each year and the tendency on the part of authors to write increasingly lengthy articles, brought about the establishment of the limitations mentioned above.

The cost of publishing a page in the JOURNAL at this time is approximately $70. If we are to operate on a self-sustaining basis, we can publish no more than four papers of approximately 8,000 words each month and live within our budget. Of course, as membership and advertising continue to increase, limitations imposed by the budget will be eased and more papers will be published.

More than 65 technical papers will be presented at the Petroleum Branch Fall Meeting in San Antonio and the Pacific Petroleum Chapter Fall Meeting in Los Angeles. Additional papers will be presented at the national AIME meeting, and a substantial number of unsolicited papers will be received in the Petroleum Branch offices. It is apparent that consistent with clarity each paper presented must occupy a minimum amount of space if maximum opportunity for publication is made available to the entire membership.

A study of the average length of technical papers published in the JOURNAL indicates that they have become longer and longer since 1951. The average length of technical papers printed in the JOURNAL in 1951 was 7.2 pages. In 1952, the average rose to 7.6 pages, and in 1953 it climbed to 9.6 pages per paper.

The Committee is aware of the two schools of thought that exist with regard to the substance of papers. At one extreme are those people who want to see only the new information published; at the other extreme are those who want a paper to be made perfectly clear to all potential readers by providing a historical treatment of the problem and inclusion of detailed data. The space established as the maximum is considered a compromise between the two extremes.

The Committee would suggest that authors who find their papers running in excess of the limits set forth above re-examine their papers to see if historical information can be reduced or descriptions of experimental procedures condensed. In many cases it is more desirable to present experimental data in graphic or tabular form. The Committee has often found that illustrations are presented which are extremely interesting but are not essential, and frequently as many as three photographs or drawings are used to illustrate the same point.

The principal objectives of an author in publishing a paper in the JOURNAL include:

(1) Presenting general information to the membership;

(2) Providing precise information for research workers in the field of the paper and for those people charged with the responsibility of adapting new information and techniques to the petroleum industry;

(3) Contributing to the permanent literature.

In general, objective No. 1 is best accomplished with an abstract. In meeting objective No. 2 the author should include such information as will permit the reader to evaluate the possibilities of using what is presented in his own work. If so, direct communication with the author is usually desirable.

The length limitations are being put into effect immediately due to the increasingly large backlog of papers which are on hand. Members of the Technology Committee are informing authors of the importance of conforming with the new limitations when soliciting papers for the Petroleum Branch Fall Meeting. Papers in excess of 8,000 words will be considered for publication, for the Committee realizes that greater space will be required for a few papers. When an author submits a paper in excess of the maximum length prescribed, he is requested to include in his letter of transmittal an explanation of the need for additional space. Both the Committee and its expert reviewers will study such papers for areas of possible condensation.

It is the opinion of the Committee that the policy outlined above will lead to more precise writing on the part of the authors, an elevation of standards for the JOURNAL and increased readability for the reader. Perhaps our entire problem would be solved if our authors would bring into bold relief that which is new and original and keep all else to a minimum. A single cut and polished diamond displayed on black cloth makes a far greater impact than a rough stone in a pan of wash gravel. ★★★

FEATURE ARTICLE

AN INEXPENSIVE MUD for DEEP WELLS

HENRY F. COFFER
CONTINENTAL OIL CO.
PONCA CITY, OKLA.

ROSCOE C. CLARK, JR.
MEMBERS AIME
THE WESTERN CO.
MIDLAND, TEX.

Abstract

Development of a new mud designed to give the desirable drilling characteristics of the conventional lime mud but without its inherent limitations is discussed. The work includes both laboratory and field testing of the mud.

The mud has been used successfully in nine wells with considerable cost reduction. It is resistant to contaminants such as anhydrite, gyp, cement, and salt water and does not gel at high temperature. Field results have shown that the mud can compete economically with low- or high-pH caustic-quebracho muds with the added advantage that it yields better gauge holes and its filtrate is not as damaging to the pay formation.

Introduction

The use of conventional lime-base drilling muds[1,2] has made possible the drilling of wells in areas where contamination from gyp, anhydrite, and salt water flows are encountered. Their desirable drilling characteristics and ease of maintenance have allowed the drilling of long sections of open hole and have often eliminated the necessity of a protective intermediate casing string. Conventional lime muds, however, suffer from several disadvantages which often make their usage impractical.

First, and of greatest importance in deeper holes, is the occurrence of high temperature gelation which prevents the successful application of various logging tools and perforating guns due to the solidification of the mud in the bottom of the hole.[3,4] Further evidence of this gelation of conventional lime muds will be more apparent in the near future as workover jobs require washover operations in order to pull the packers set in lime mud.

Of almost equal importance is the high cost of the maintenance of a lime mud. This eliminates or sharply curbs its usage in areas where contamination from gyp, anhydrite, and salt is light enough that it can be successfully handled by use of low-pH or high-pH caustic-quebracho muds. Unfortunately, its elimination from a cost standpoint also limits the use of muds with filtrates containing calcium ion which is effective in reducing the swelling and sloughing of shales, thus yielding better gauge holes.

A third disadvantage of the conventional lime mud is its lack of versatility from a logging standpoint. Since the mud is always saturated with lime, the pH must be 12.5 or higher, eliminating all possibility of high resistivity.

In lieu of the outlined limitations of conventional lime muds, it appears that the industry has need of a drilling mud which will provide the desirable drilling characteristics of the lime mud without the inherent limitations of high temperature gelation, high maintenance costs, and lack of variable resistivity. It is the purpose of this paper to present the results of the laboratory development and field testing of such a mud.

Laboratory Development of Mud — Effect of Chemical Thinners

The first step in the development of a substitute mud for conventional lime muds was a comprehensive determination of the effect of available chemical thinners on muds containing lime. In these experiments, the mud used was a 6 per cent slurry of Wyoming bentonite in water to which was added 5 lbs/bbl of lime. The effect of the available chemical thinners on the viscosity was determined at varying concentrations of caustic soda. The results of these tests are shown in Figs. 1, 2, and 3 where the viscosities are plotted as a function of the chemical thinner concentration at constant caustic content.

A study of Figs. 1, 2, and 3 shows an important difference between the thinning effect of quebracho and of calcium ligno-sulfonate.. Both chemicals apparently have maximum effectiveness at between 1 and 2 lbs/bbl with further addition of chemical producing little if any effect; however, the effect of the addition of caustic soda on the results obtained with the two chemicals is completely different, an increase in caustic aiding the thinning efficiency of quebracho but having no effect on the thinning efficiency of calcium ligno-sulfonate.

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office Aug. 17, 1953. Paper presented at the Petroleum Branch Fall Meeting in Dallas Oct. 19-21, 1953.

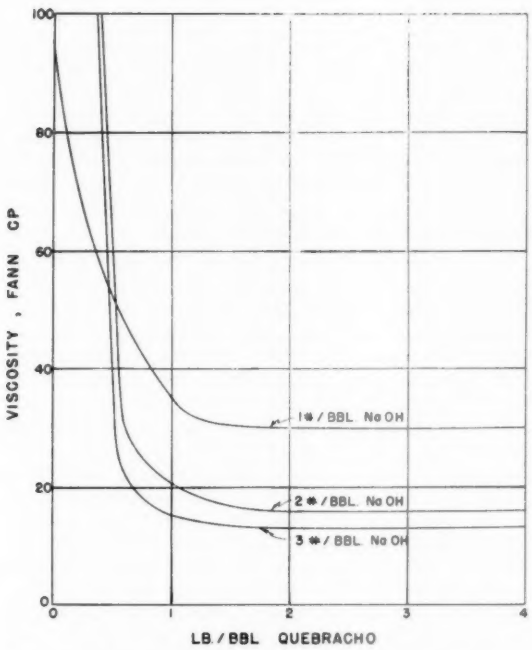


FIG. 1 — EFFECT OF QUEBRACHO ON THE VISCOSITY OF 6 PER CENT GEL MUD CONTAINING 5 LBS/BBL LIME.

Effect of Lime

The second phase of the study was the determination of the effect of lime concentration on a mud. A series of mud samples was prepared containing 6 per cent gel which was completely hydrated. To one series of the samples containing fixed amounts of chemical thinner and caustic soda were added various amounts of lime. The samples were stirred and viscosities measured after aging one day, two days, one week, two weeks, and one month. Similar series of samples were prepared using different concentrations of caustic soda, the thinner concentration being held constant at 2 lbs/bbl. (Figs. 1, 2, and 3 indicated that further chemical would have no effect.) Fig. 4 illustrates the results of the two-day viscosity tests (when the samples proved to be almost at equilibrium).

From Fig. 4 it can be shown that the maximum thinning efficiency of lime lies between ½ and 2 lbs/bbl. In all cases, further additions of lime resulted in increased viscosities, especially in the samples where quebracho was used with only a small amount of caustic. Noteworthy, too, is the fact that the addition of more caustic above 1 lb/bbl had no effect in systems using the calcium ligno-sulfonate as the thinner. Additional laboratory results have shown that this is true even when the caustic content is carried as low as .2 lb/bbl, which makes possible the formulation of a new lime mud with very low caustic content by use of calcium ligno-sulfonate as the chemical dispersant.

Sodium Hydroxide and Resistivity

Since one of the objections to conventional lime-base muds has been their low resistivities, an investigation was made of the effect of caustic soda on resistivity. Fig. 5 shows the effect of changing the caustic concentration on the resistivity of a 6 per cent gel mud. As shown in Fig. 5, the resistivity will always be low if the caustic concentration is greater than 1 lb/bbl.

Formulation and Testing of the New Mud

From the preceding data, it was concluded that if a mud with low caustic content is desired, the most efficient thinner for use in a lime system is calcium ligno-sulfonate. Further, if the maximum thinning efficiency from lime is desired, a concentration of from ½ to 2 lbs/bbl should be used. Accordingly, a laboratory mud was mixed using 2 lbs/bbl of lignox, 2 lbs/bbl of lime, and .2 lbs/bbl of caustic.

Testing of the laboratory mud showed that it had a resistivity of 2.6 ohmmeters; would tolerate gyp, anhydrite, or cement; and could withstand 50,000 to 75,000 ppm of salt. Further, the mud would not gel at high temperature, a sample heated at 350°F for six months being thinner than when originally mixed. The behavior of this mud at high temperature compared with that of a conventional lime mud is shown in Fig. 6 which presents a plot of viscosity versus heating time of the two muds.. Fig. 6 illustrates the considerable difference in gelation characteristics between this new mud and ordinary lime-base muds.

Field Tests of Conoco M-1 Mud

Louisiana Test

From the laboratory results, a field test of the mud, which has since been termed Conoco M-1 Lime Mud, was made to determine the dollar savings which could be obtained from its use. The first test of the M-1 Lime Mud was made in well A, a 10,630-ft deep development well located a few miles from Abbeville.

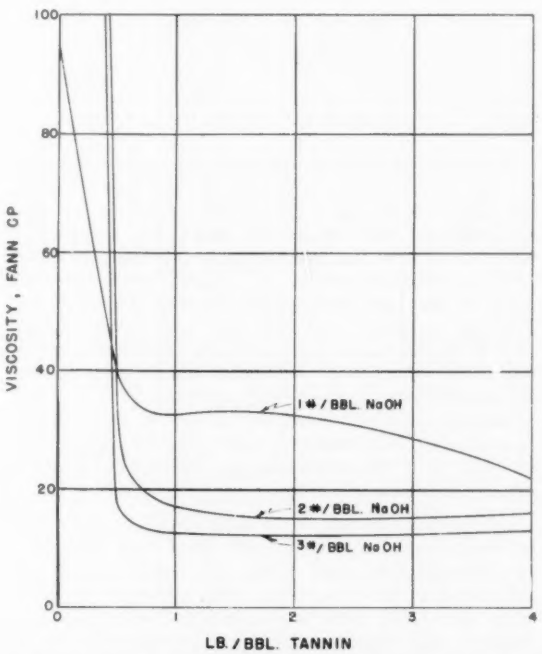


FIG. 2 — EFFECT OF TANNIN ON THE VISCOSITY OF GEL MUD CONTAINING 5 LBS/BBL LIME.

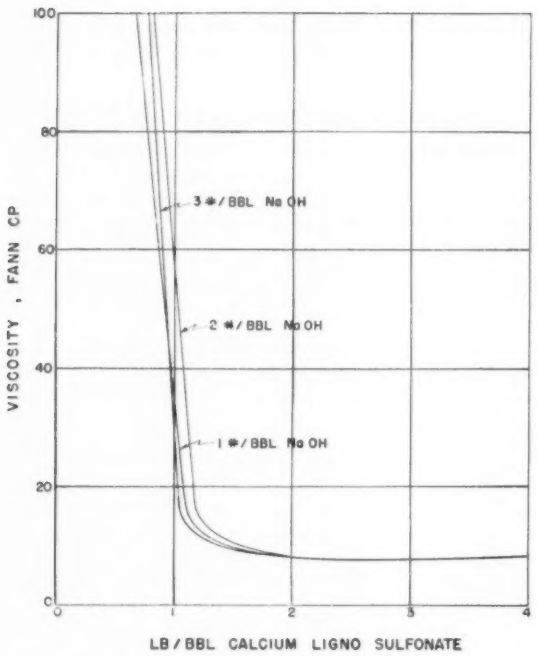


FIG. 3 — EFFECT OF CALCIUM LIGNO SULFONATE ON THE VISCOSITY OF 6 PER CENT GEL MUD CONTAINING 5 LBS/BBL LIME.

La. Comparison of mud costs during the drilling of this and offset wells is give in Table 1.

TABLE 1 — COMPARISON OF MUD COSTS USING NEW MUD AND OTHER MUDS IN THE SAME FIELD

	Type Mud	Total Depth	Mud and Chemical Costs
Well A	Conoco M-1 Lime	10,630 ft	$ 4,396
Well B	Caustic-Quebracho	11,149 ft	10,883
Well C	Red Lime	12,523 ft	34,076
Well D	Caustic-Quebracho	10,855 ft	9,816
Well E	Caustic-Quebracho	11,352 ft	6,512

The cost difference is apparent, the well drilled with the M-1 Lime Mud being drilled for approximately two-thirds of the mud cost of the cheapest and less than half the mud cost of the others. The comparison with well C may not be completely justified, since that well was finished with a 15.7-lb/gal. mud; however, costs on this well to the 10,600-ft level, to which the mud was weighted to 11.6 lbs/gal., were approximately $9,500. Furthermore, daily chemical treatments excluding weight material on well C for the six days following breakover to a lime mud averaged $122 per day in comparison with $33 per day on well A. These figures would indicate that the M-1 Lime Mud effected savings on this well of approximately $4,600 over those usually drilled in this field.

Of further interest is a comparison of the daily treating cost of the M-1 Lime Mud with that of a conventional lime mud which was being used in the same field at the same time. Daily chemical treatment costs for 1,600 bbls of M-1 Lime Mud was $33, whereas daily chemical treatment of the 890 bbls of conventional lime mud was $94. This indicates that even further savings would be realized in holes which required longer drilling periods.

Canada Test

M-1 Lime Mud has been used in drilling three wells in Canada where conventional lime muds have had little success. Two of these were in the Leduc Region where an 80-ft section of anhydrite lies just above the pay section, and the third was near Olds where the anhydrite bed is approximately 500-ft thick. In all cases, the mud was converted to M-1 Lime Mud a few hundred feet above the anhydrite section with no trouble experienced in the breakover.

Cost comparisons are available on only the two wells near Leduc. On these the M-1 Lime Mud bills totaled approximately $1,700 each for both wells. This compares with the usual mud cost of wells in this field of approximately $1,900. The cost reduction, however, does not give the complete story since the test wells were completed with water losses of 3.4 and 2.6 cc compared with the usual 8 to 15 cc water losses of the muds used in previous wells. In all cases starch was used as the water loss reducing agent (both M-1 Muds and ordinarily used caustic-quebracho or gyp muds). An extra cost factor was introduced with the M-1 Muds since $500-$600 worth of starch was required to bring the water loss down from 10-12 cc to the desired values just prior to penetrating the pay section. Thus the total mud bill for a mud with comparable properties to the ordinary muds (8-15 cc water loss) would have varied from $1,100 to $1,200 compared to the usual $1,900. In these instances the extra savings afforded by the use of the M-1 Mud were sacrificed in order to achieve a mud with a lower filtrate loss into the pay formation.

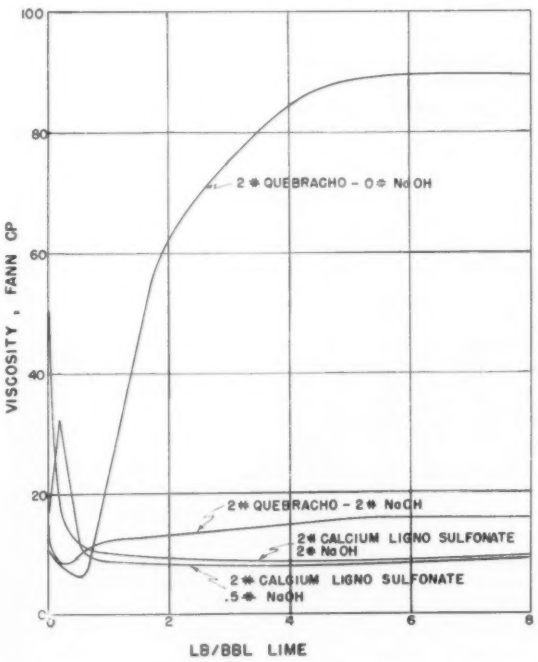

VISCOSITY , FANN CP
2 # QUEBRACHO - 0 # NaOH
2 # QUEBRACHO - 2 # NaOH
2 # CALCIUM LIGNO SULFONATE
2 # NaOH
2 # CALCIUM LIGNO SULFONATE
.5 # NaOH
LB/BBL LIME

FIG. 4 — COMPARISON OF THE EFFECT OF LIME ON VISCOSITY OF 6 PER CENT GEL MUDS TREATED WITH CAUSTIC AND QUEBRACHO AND CALCIUM LIGNO SULFONATE AND CAUSTIC, MEASURED TWO DAYS AFTER MIXING.

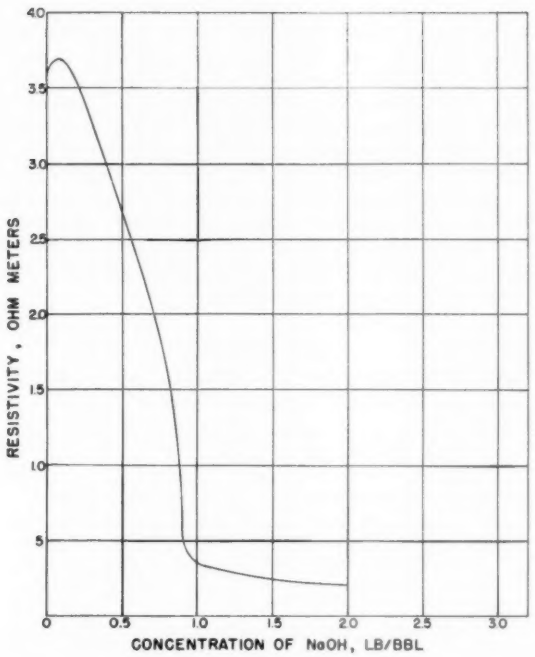


FIG. 5 — EFFECT OF CONCENTRATION OF NaOH ON THE RESISTIVITY OF A 6 PER CENT GEL MUD CONTAINING 2 LBS/BBL CALCIUM LIGNO SULFONATE.

No difficulty was encountered either during the breakovers or in the use of the M-1 Lime Mud on these wells. On the first well, no treatment was allowed in the mud during the drilling of the anhydrite in order to determine its effect on the mud. While drilling the first 10 ft of anhydrite, the viscosity increased from 46 to 52 cp and then gradually drifted back to its original value as drilling progressed. The mud developed some 10-minute gel strength, but this was easily lowered by chemical after the anyhdrite drilling had been completed.

An even better test of the ability of the mud to tolerate anyhdrite was in the Olds well where 500 ft of anhydrite was drilled. This, too, was completed with no difficulty; though again the 10-minute gel of the mud increased considerably. (Light treatment with caustic-quebracho, however, kept the properties at the desired value.)

The Olds well was interesting also from the standpoint of drilling characteristics. Before the breakover to the M-1 Lime Mud, considerable difficulty was encountered on trips, with the one just before breakover requiring 24 hours. On the first trip after the breakover, there were several feet of fill in the bottom of the hole. From there on until the completion of the well, however, no caving or tight places were encountered; and trips were made easily and rapidly. This helps to illustrate the superiority of this new mud over the conventional muds used in that area in the reduction of sloughing of shale into the hole.

History of Edson Well

The most interesting well in which the mud has been tested was a deep wildcat near Edson, Canada. In this well surface string was set at 507 ft and drilling continued with a low pH caustic-quebracho mud. Considerable caving and sloughing shale was encountered from 4,500 ft down with trips becoming more difficult. Troubles increased with depth and finally the hole was lost at 9,630 ft due to stuck drill pipe. The well was plugged back to 5,200 ft and hole sidetracked. Drilling continued with the low pH caustic-quebracho mud and the troubles increased as before. During the entire troublesome period of this well, a service company mud engineer remained on location to keep the mud in optimum condition. Low water losses of 3-5 cc were maintained but sloughing continued.

A sample of the sloughing shale was analyzed by x-ray diffraction in the laboratory and found to contain kaolinite and illite. It was then decided to try the M-1 Lime Mud since the calcium filtrate would be expected to reduce the swelling of the illite. Accordingly, a string of 9⅝-in. casing was set at 7,200 ft and the mud converted to the M-1 Lime Mud. Since that time, drilling has proceeded without any trouble for the past two months with the mud properties as follows: weight, 13.5; viscosity, 60-70 seconds; water loss, 3-4 cc; and pH, 11-11.5. Very little sloughing has been encountered, and trips have been made with no trouble.

Drilling is now continuing below 10,400 ft in chert with good prospects of completing the well to the proposed depth; and thus in this instance, the use of M-1 Lime Mud has allowed the drilling of a well which would probably not have been possible with the conventional muds in that area. Further, it is doubtful if a conventional lime mud would have been successful here; since in the Edson mud systems, the addition of more than 2 lbs/bbl of lime resulted in the solidification of the mud.

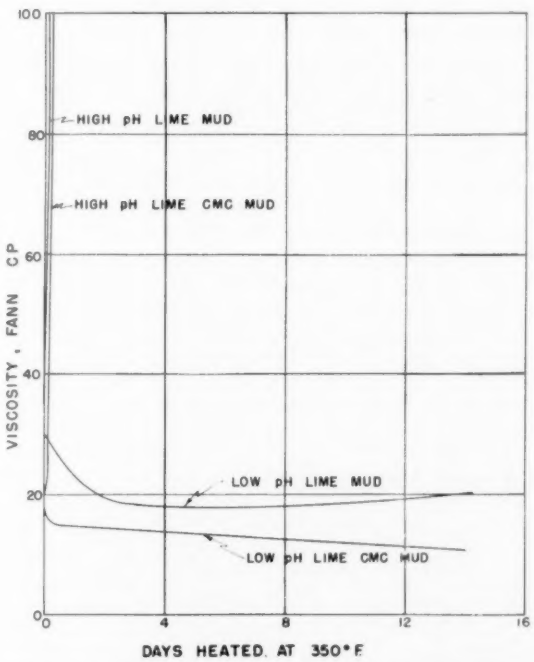


FIG. 6 — EFFECT OF HEATING AT 350°F ON VISCOSITIES OF MUDS MADE FROM 6 PER CENT GEL, 94 PER CENT WATER.

Present Field Status of Conoco M-1 Lime Mud

In the Gulf Coast area, at present Continental has four wells being drilled with Conoco M-1 Lime Mud. Two of these are near Houston and the other two near Morgan City, La. No trouble has been encountered with the mud either in the breakover or in keeping it in condition after breakover. In one of the wells in Louisiana, the mud was used while drilling through 700 ft of cement with no trouble. Maintenance has been as easy as that of a lime mud, the only difference being that considerably less chemical and lime are used. Tests are presently planned in North Texas, Oklahoma, and Wyoming since it is believed the mud can economically compete with muds used in these areas.

Discussion

Field tests to date indicate that the M-1 Lime Mud may replace conventional lime muds. It is much more versatile than the lime mud in that it can be treated to meet any desired situation. For example, if cement or anhydrite is to be drilled, the pH of the mud may be raised to 12 or above by the addition of caustic soda to reduce the solubility of the cement and anhydrite. Similar procedure would be employed if salt water was encountered since the mud will tolerate more salt as the pH of the mud is raised.

The M-1 Lime Mud is more versatile and less expensive than the low-pH lightly-treated lime-base mud recently described by T. M. Watkins.[4] The calcium ligno-sulfonate is used as a dispersant during the breakover enabling the use of quebracho as a thinner should it be necessary at any time after the breakover to obtain additional thinning. The reduction in cost is due to the lesser amounts of chemicals used in controlling the M-1 Lime Mud.

Breakover to the new mud is made with no difficulty while drilling is progressing. It can be converted any time after the surface string has been set. The breakover is made ordinarily with 1.5 to 2 lbs/bbl of calcium ligno-sulfonate, .2 lb/bbl of caustic, and 1 lb/bbl of lime. This yields a mud with a pH of from 11.0 to 11.5. Water loss is controlled at the desired value by the use of CMC.

Control of M-1 Lime Mud is by use of the chemicals used regularly in lime muds. The only difference is in the amounts used. For example, the lime treatment for this mud will range from 50 to 300 lbs per day, depending upon the hole size and penetration rate. Viscosity control is maintained as desired by quebracho or calcium ligno-sulfonate with possibly 25 lbs of caustic used per tour. The pH is maintained between 9.5 and 11.5, depending upon the lime content desired. A typical tourly treatment for a mud would be 50 lbs of lime, 50 lbs of quebracho, and 25 lbs of caustic.

The small amounts of chemical treatment required for this mud makes it possible for it to economically compete with the low-pH and high-pH caustic-quebracho muds. This is especially true since the mud has better drilling characteristics and eliminates much of the tight-hole troubles frequently encountered with the caustic-quebracho muds. Further, the reduction of the clay swelling by the high calcium ion concentration in the filtrate makes M-1 Lime Mud a better mud to use when drilling pay sections. Laboratory and field test results indicated that this mud can be weighted to as high as 19.5 lbs/gal. without risk of the weighting material falling out of suspension.

Conclusions

Based on the results of laboratory and field tests conducted to date, it is concluded that:

1. The M-1 Lime Mud is superior to other lime-base muds from the standpoint of:
   a. Cost
   b. Versatility
   c. Control of resistivity
   d. Gelation
2. The M-1 Lime Mud is superior to caustic-quebracho muds from the standpoint of:
   a. Prevention of shale sloughing
   b. Less damage to pay formations

Acknowledgment

The authors wish to express their appreciation to members of the Continental Oil Co. and the Hudson's Bay Oil & Gas Co., Ltd., Production Departments for their help in conducting field tests, to J. J. Reynolds for helpful suggestions and criticisms, and to the management of Continental Oil Co. for permission to publish this paper.

References

1. Lancaster, E. H., and Mitchell, M. E.: "Control of Conventional and Lime-Treated Muds in Southwest Texas," *Trans.* AIME (1949), **179**, 357.
2. Goins, W. C., Jr.: "A Study of Limed-Mud Systems," *Oil and Gas Jour.* (Jan. 19, 1950), **48**, 52.
3. Gray, C. R., Neznayko, M., and Gilkeson, P. W.: "Some Factors Affecting Solidification of Lime-Treated Muds at High Temperatures," *Oil and Gas Jour.* (July 28, 1952), **51**, 265.
4. Watkins, T. E.: "A Drilling Fluid for Use in Drilling High Temperature Formations," paper presented at the Spring Meeting, API Southwestern District, Mar. 4, 5, and 6, 1953, Fort Worth, Tex. ★★★

FEATURE ARTICLE

DUAL PUMPING with FIVE STRINGS of TUBING

F. C. EDWARDS
MEMBER AIME

HONOLULU OIL CORP.
SUNDOWN, TEX.

Introduction

Dual pumping, and its accompanying problems, has been a subject of continuing interest to the oil industry. From an economic standpoint, a substantial savings in drilling and equipment costs can be realized by the use of dual completions.

The problems encountered in the design and installation of the dual pumping equipment in this particular field were no different from those likely to be met in any field where dual pumping might be considered. For succesful installations in this field the objectives of the designers were:

1. To utilize conventional hydraulic pumping equipment, thereby standardizing all pumping operations.

2. To obtain high pumping efficiencies from both zones by completing the upper zone with no packer and venting the gas in the lower zone from beneath the packer to the surface.

3. To pump each zone independently without communication between the two as required by the Oil & Gas Division of the Texas Railroad Commission.

These three objectives have been accomplished and all presently-installed dual pumps of the type to be discussed are operating successfully. This type of dual pumping completion eliminates many of the problems encountered with "down the hole" trigger mechanisms. Each zone may be pumped in a conventional manner and both zones can be pumped simultaneously or individually.

Well Completions

Dual pump installations have been installed in the Prentice field and the Prentice 6,700-ft field located in Yoakum and Terry Counties, Tex. The pay zone in the Prentice field is the Glorietta (limestone of Permian Age), at a total depth of approximately 6,000 ft. The pay zone in the Prentice 6,700-ft field is the Clearfork (limestone of Permian Age), at a total depth of 6,700 ft. Most wells in both the Glorietta and Clearfork undersaturated pays were completed initially as pumping wells. Prior to installation of dual pumping equipment in wells in these fields, all wells were twinned, that is a single well was drilled to each pay zone.

The casing used in these single wells in most cases was 8⅝-in. and 5½-in. In order to accommodate the three strings of tubing necessary for the dual pump installation, it was necessary to alter the casing program from 8⅝-in. intermediate string cemented at approximately 2,500 ft, and 5½-in. liner for the oil string cemented at approximately 6,500 ft, to 9⅝-in. and 7-in. It should be emphasized that the minimum weight of 7-in. casing for the depth was necessary to obtain a maximum inside diameter to accommodate the aforementioned three strings of tubing and clamps.

The 7-in. casing was hung from the 9⅝-in. casing by the use of a positive-seal liner hanger at a depth of approximately 2,400 ft. The two strings of casing could have been cemented together.

The lower zone (Clearfork) was an open hole completion and was acidized in a conventional manner below a hook wall packer. The upper zone (Glorietta) was then perforated and a retainer production packer was set in the casing between the two pay zones at the top of the lower pay. An anchor packer was set above the perforations in the upper zone. The bull-plugged anchor with the production packer pack-off elements and bumper sub were seated in the retainer production packer, and the upper zone was then acidized between the anchor packer and the retainer production packer. This procedure allowed the production packer packing elements to be tested under pressure prior to the installation of the dual pumping equipment.

Selection and Design of Equipment

In order to utilize conventional equipment for pump-

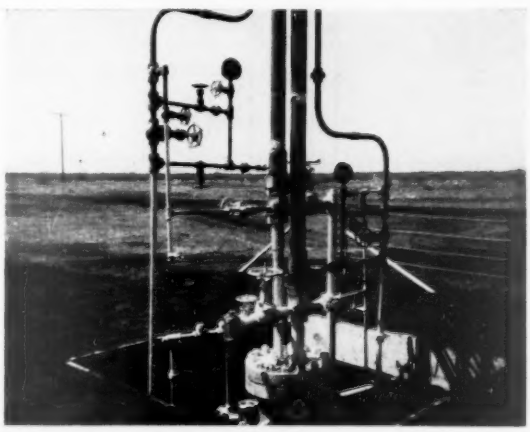


Fig. 1 — Completed Wellhead for Dual Pumping.

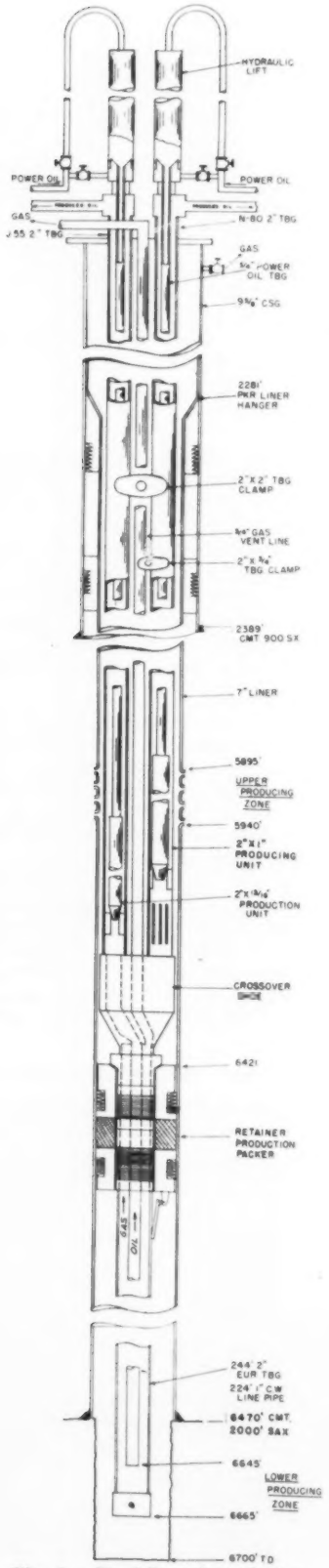


Fig. 2 — Dual Zone Installation.

ing from two zones and to vent gas from beneath the permanent retainer production packer, three parallel strings of tubing were required. These consisted of two strings of 2-in. EUE tubing and one string of either ¾-in. EUE or 1-in. continuous weld line pipe as gas volume required. It was necessary to design and manufacture special equipment for this installation. This equipment was:

1. A cross-over shoe, which is an integral tool used in this method of dual pumping. It was designed to: (a) anchor the three parallel strings of tubing; (b) change over from a single string tail pipe to the three parallel strings; (c) permit passage of fluid from the lower zone to the lower pump intake; and (d) permit passage of gas from the lower zone to the surface through the ¾-in. parallel string of tubing.

2. Tubing clamps, 2-in. x 2-in., which were used to clamp together the two strings of 2-in. tubing. (2-in. x ¾-in. clamps are standard equipment).

3. A slip-type tubing head, that was designed to suspend two strings of tubing and pack off the third or "macaroni" string.

Other equipment necessary was: (a) a complete string of N-80 tubing used as the carrying string for both the J-55 2-in. tubing and the ¾-in. tubing. (These two strings of tubing were clamped to the N-80 tubing by the use of 2-in. x 2-in. and 2-in x ¾-in. clamps. The total weight of the three strings with clamps, cross-over, and tail pipe was approximately 73,000 lbs or the equivalent of 15,532 ft of 2-in. EUE tubing.

Running of Pumping Equipment

To assure a successful job the following precautionary measures were taken. The N-80 tubing was inspected by external magniflux and internal optiscope to detect any metallurgical flaws in either the tubing or the couplings. Each joint of 2-in. tubing was hydrotested to 5,000 lbs as run, to insure that no leaks were present in the joints, threads, or couplings.

When running this large amount of equipment into the hole, extreme caution was exercised and careful supervision was maintained in order to minimize the possibility of a fishing job or a re-run because of leaks in any string of tubing.

The first equipment run was 244-ft of 2-in EUE J-55 tubing. Inserted in the above and connected to the cross-over shoe was a string of 224-ft of 1-in. non-upset line pipe. The 1-in. served as an oil production intake string for the lower zone pump. The annular space between the ID of the 2-in. EUE and OD of the 1-in. non-upset tubing served as gas outlet to the ¾-in. EUE gas vent tubing. The above 2-in. EUE tubing was supported by attachment to the retainer production packer locator sub and seal nipple (Fig. 2). An effective positive seal was maintained between the two producing zones by the retainer production packer and the seal nipples.

The cross-over shoe was screwed directly into the locator sub. A pump seating shoe was then placed in the cross-over shoe outlet that connects to the lower zone.

A 6-ft slotted gas anchor was screwed into the blanked-off 2-in. connection in the cross-over shoe. A pump seating shoe for the upper zone was placed in the top of the 6-ft slotted gas anchor. The N-80 tubing, which must carry the entire weight of the three

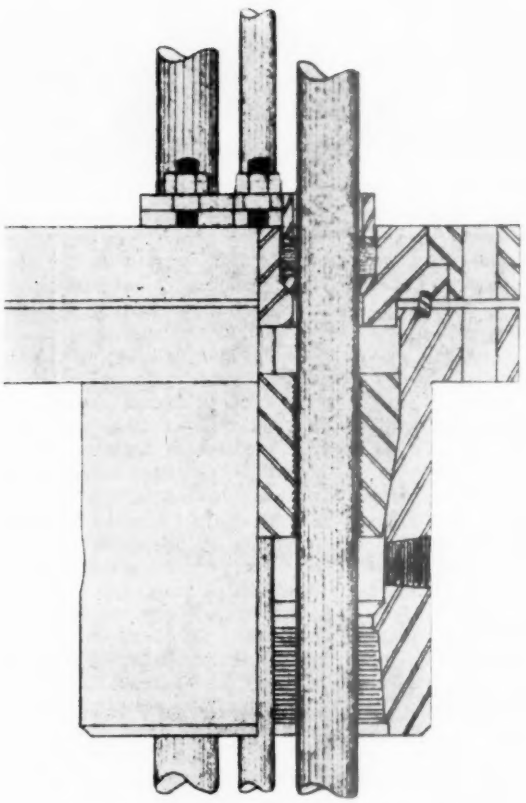


Fig. 3 — Cut-away View of Tubing Head.

strings of tubing, was started at this point. A 4- to 6-ft difference in length between the couplings of the two strings of 2-in. tubing was necessary to allow sufficient clearance to provide ease of installation with tools used. This spacing was established by the 6-ft slotted gas anchor and maintained throughout the installation by use of N-80 tubing subs.

The ¾-in. tubing was screwed into the top of the cross-over joint and joints were added as needed, with no specific regard to spacing other than to prevent any couplings from being adjacent.

The shorter or 2-in. J-55 tubing string was clamped to the 2-in. N-80 string with 2-in. x 2-in. cast semi-steel clamps set above the N-80 upset. On the first three joints above the shoe two clamps were used per joint to assure rigidity; above this, one clamp per joint.

The ¾-in. tubing was clamped to the 2-in. N-80 tubing with 2-in. x ¾-in. clamps set approximately in the middle of each joint of N-80 tubing.

The two parallel strings of 2-in. tubing were suspended from the tubing head with slips. The slip body contained an opening for the ¾-in. tubing. All three strings of tubing were then packed off in the tubing head with a seal ring and hycar packing.

After the parallel strings had been run, a conventional hydraulic pump was installed in each string of 2-in. tubing. (A conventional installation consists of a hydraulic pump attached to a string of ¾-in. tubing which is placed inside the 2-in. tubing). This procedure was the same as any single well completion.

After the pumps were seated, the necessary well head equipment was installed, hydraulic lifts erected and connected, and power oil lines laid to each lift. Both zones were then pumped as individual wells, each entirely independent of the other. Individual production tests and the accompanying pressure data definitely established the absence of communication between the two different pay zones.

Cost Analysis

The successful operation of these dual pump installations has made it possible to produce from two pumping pay zones without the expense of drilling an additional well. It is believed that this will be true for the entire producing life of the oil pays. An over-all saving of approximately $50,000 as of April, 1954, was effected through use of the first installation of this type.

Table 1 shows the amount of material which would be necessary in drilling and equipping single wells as compared to this type of dual pumping completion.

TABLE 1 — MATERIALS NECESSARY TO DRILL AND EQUIP SINGLE WELL VERSUS DUALLY-COMPLETED WELLS.

	Single 6,000-ft well	Single 6,700-ft well	Total	Dual Completion
Feet of hole drilled	6,000 ft	6,700 ft	12,700 ft	6,700 ft
8⅝-in. intermediate string of casing	2,500 ft	2,500 ft	5,000 ft	None
5½-in. liner or oil string of casing	3,500 ft	4,100 ft	7,600 ft	None
9⅝-in. intermediate string of casing	None	None	None	2,500 ft
7-in liner or oil string of casing	None	None	None	4,100 ft
Sax cement	2,400 sax	2,850 sax	5,250 sax	2,950 sax
2-in. J-55 tubing	6,000 ft	6,700 sax	12,700 ft	6,700 ft
2-in. N-80 tubing	None	None	None	6,500 ft
¾-in tubing	6,000 ft	6,700 ft	12,700 ft	19,500 ft
1-in. tubing	None	None	None	200 ft
Retainer production packer	None	None	None	1
Cross-over shoe	None	None	None	1
2-in. by 2-in clamps	None	None	None	210
2-in. by ¾-in. clamps	None	None	None	210
Tubing head	1 standard	1 standard	2 standard	1 special
Tubing inspection	None	None	None	6,500 ft
Hydrotest tubing	None	None	None	13,000 ft
Hydraulic lifts	1	1	2	2

Summary

A new method for dual zone pumping has been devised and put into successful operation. It incorporates the use of conventional pumping equipment, permits separate and independent pumping of each of two zones from a single well bore, innovates separate gas relief from each zone, and allows the operator to produce both zones simultaneously. One well takes the place of two wells.

Acknowledgments

Of the many to whom the author feels indebted for the success of the above installation he particularly expresses his gratitude to the Brown Oil Tool Co., Gulf Coast Machine & Supply Co. (Gulfco), and K. D. Snedeker of Kobe, Inc., for cooperation and assistance in the design and manufacture of the special equipment. He also expresses his appreciation to A. S. Donnelly, B. Craddock, T. C. Williams, Jr., B. A. Guerry, John Gould, Jr., G. B. Evans, all of Honolulu Oil Corp., for helpful comments, suggestions, criticisms and supervision of various phases of the above described installation. The management of Honolulu Oil Corp. is thanked for permission to publish this article. ★★★

JOE B. ALFORD

EXECUTIVE SECRETARY
PETROLEUM BRANCH, AIME

Growth of Petroleum Branch

The day that brought the discovery of Spindletop, January 10, 1901, was a day that has had a significant influence on the AIME. It laid the cornerstone for the development, within the framework of AIME, of a professional group that has since become the Petroleum Branch of the Institute.

Anthony F. Lucas was an Austrian who was trained as a mining engineer in his native country. He came to this country in 1879, and became a member of AIME in 1895. His discovery of Spindletop focused national attention upon him, which, to some extent, was reflected on AIME: six weeks after his discovery, he presented a paper at an AIME meeting entitled, "The Great Oil Well Near Beaumont, Texas." This paper was undoubtedly influential in causing mining engineers of the day to become interested in the oil industry. Engineering was a part of this industry from the beginning, and as the need for it became apparent, the mining engineer began to turn to the industry as a new field in which to practice his art. Because of this, and the continuing personal influence of Lucas and others, it was an entirely natural course that the AIME should become the forum for the exchange of engineering knowledge on the oil industry.

Engineering thought developed, and about 1913 the new art of petroleum engineering began to emerge. It is significant that Anthony F. Lucas came into the picture again that year through the establishment of a Technical Committee on Oil and Gas within the AIME. He was the first chairman of the committee, and after holding the post for a few years was succeeded by A. F. L. Bell, Ralph Arnold, and E. DeGolyer. This committee was expanded into the formal organization of the Petroleum Division of AIME in 1922. Thus, the Committee and the Petroleum Division, aided by the influence of its leaders and other factors, caused the development of petroleum engineering to flourish within the framework of AIME rather than as a separate engineering activity.

H. Foster Bain, then Secretary of the Institute, stated in the Foreword of the 1925 Petroleum *Transactions* volume that 885 of the 9,000 members of the Institute then were primarily interested in petroleum.

This fact establishes a basis for determining the growth pattern of the Petroleum Branch within AIME. We have not found that any other precise measurement of the number of Petroleum members of the Institute was made until 1946, when Secretary A. B. Parsons reported in the Seventy-fifth *Anniversary Volume* that those interested primarily in petroleum were 17.1 per cent of the Institute. The growth of the total AIME membership is precisely recorded, and by starting with the Petroleum membership as 10 per cent of the Institute in 1924, we can calculate a gradual increase in the percentage of petroleum members to 17.1 per cent in 1946 and apply this scale to the Institute membership to get the Branch membership. The next known point is 23 per cent in 1950, and the advent of financial accounting by Branches made possible the precise measurement of the Metals, Mining, and Petroleum Branch membership in the years since. The petroleum membership has advanced rapidly; by mid-summer it will have increased 50 per cent in the past four years, and we are now almost 27 per cent of the Institute. The growth pattern (including students) is shown in Fig. 1.

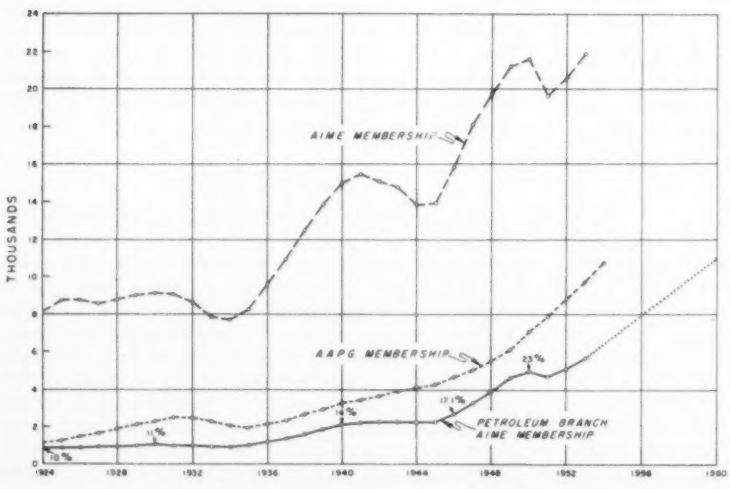


Fig. 1 — Growth of AIME, AAPG, and Petroleum Branch, AIME membership.

Many factors have caused this growth; the establishment of Assistant Secretary of the Institute for Petroleum in 1938; the founding of the Division office in Dallas in 1946; the founding of the Petroleum Branch and our present publications in 1949; the growth and acceptance of petroleum engineering in the oil industry in post-war years; the creation of new local sections for petroleum members, and by no means least, the creation of a professional home for petroleum engineers within the Petroleum Branch of the Institute.

We think the future is almost unlimited. We believe there are perhaps 5,000 engineers in the oil industry who ought to be members of the Institute but who are not members now. We predict a membership of 11,000 for the Branch by 1960. We seek this increased membership, not for the sake of greater numbers, but for the good that it can do for all members, for the oil industry and the nation. It seems to us that a real challenge exists here for each member to do his part to help the Petroleum Branch and the Institute to grow into the greater organization that it can be in the future. ★★★

What's NEW

In Perforating, Logging, and Fishing Tool Services

McCULLOUGH
NEW SERVICES • NEW TOOLS
NEW WAYS OF DOING THINGS

Latest News About New Tools, Techniques and Services

Sharpshooting Thin Zones

Made Practical by Pin-Point Accuracy of the...

McCULLOUGH

RADIATION WELL LOGGER

(GAMMA RAY AND NEUTRON LOGS)

- Measures and defines potentially productive intervals—thick or thin. Very thin beds would normally be averaged out by longer counters.
- Efficiency in measuring gamma radiations approaches 100%. It is 100 times more sensitive per unit of volume than other type counters.
- Extreme stability of equipment enables duplication of successive runs in same well with accuracy.
- Calibrated in International Units for accurate quantitative interpretation.
- All controls at surface—log detail can be varied —no baseline drift—no sensitivity drift—simultaneous recording of collar log.

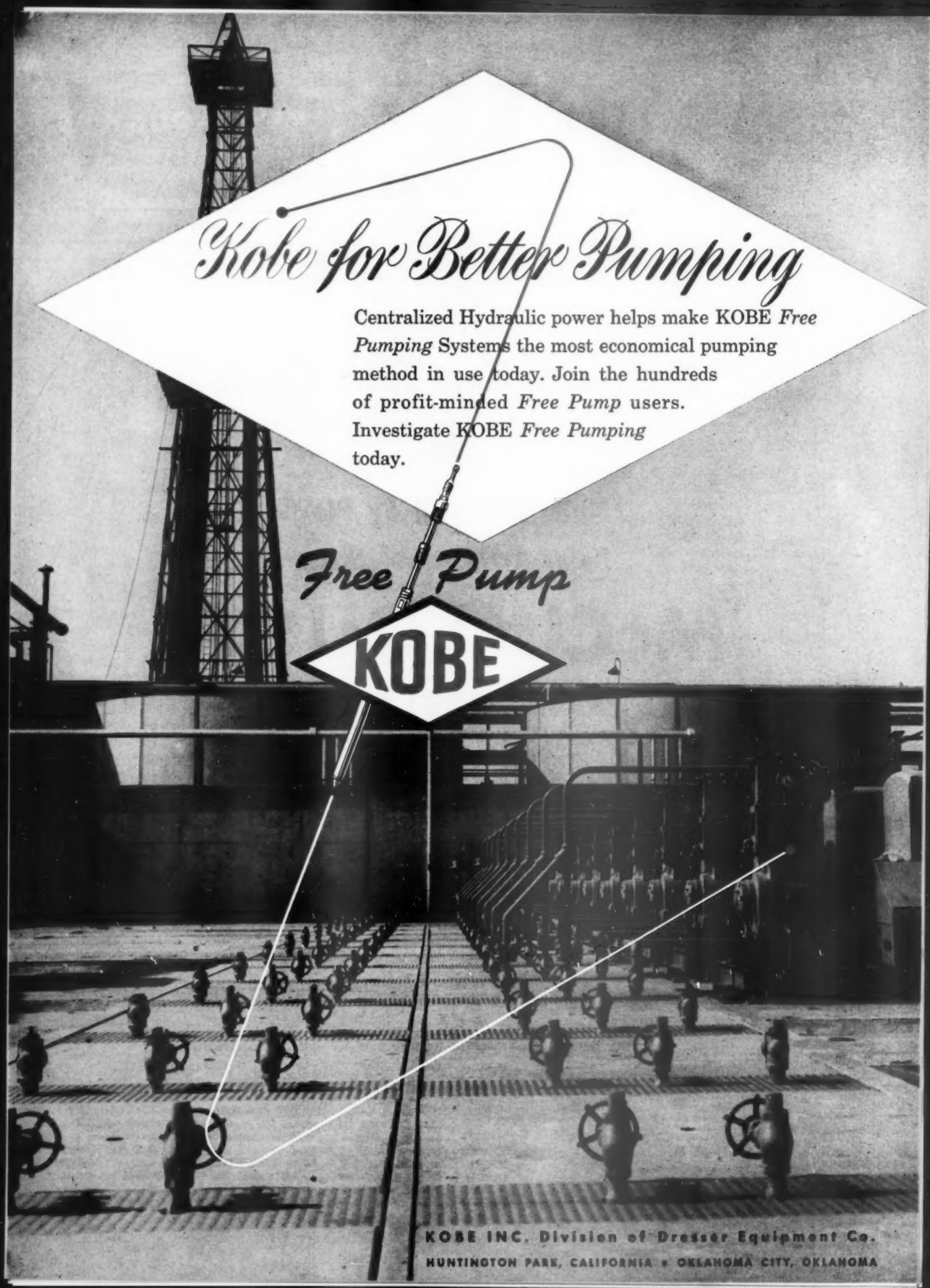
If you are not using this **newest** McCullough service, ask to see a log from your area, or write for detailed information.

For Best Results — Log AND Perforate — by McCullough

PERFORATING, RADIATION LOGGING, AND FISHING TOOL SERVICE—ANYWHERE—ANYTIME.

McCULLOUGH TOOL COMPANY
5820 South Alameda Street, Los Angeles 58, California
405 McCarty Street (P. O. Box 2575) • Houston, Texas
CABLE ADDRESS: MACTOOL
EXPORT OFFICE: Los Angeles, California
CANADA: Edmonton, Calgary, Grande Prairie, Alberta; Regina, Sask.
VENEZUELA: United Oilwell Service Co., S. A.; Caracas, Anaco, Maracaibo

SERVICE LOCATIONS: TEXAS: Houston, Snyder, Alice, Cisco, Corpus Christi, McAllen, Odessa, Tyler, San Angelo, Victoria, Wichita Falls, Luling, Beaumont, Sherman, Midkiff, El Campo. **OKLAHOMA:** Oklahoma City, Guymon, Healdton, Hominy, Wewoka. **ARKANSAS:** Magnolia. **MISSISSIPPI:** Laurel. **NEW MEXICO:** Hobbs. **KANSAS:** Great Bend. **WYOMING:** Casper, Cody, Newcastle. **CALIFORNIA:** Los Angeles, Avenal, Bakersfield, Ventura. **LOUISIANA:** Houma, Lake Charles, New Iberia, Shreveport. **COLORADO:** Sterling. **NORTH DAKOTA:** Williston. **UTAH:** Vernal.


Kobe for Better Pumping
Centralized Hydraulic power helps make KOBE Free Pumping Systems the most economical pumping method in use today. Join the hundreds of profit-minded Free Pump users. Investigate KOBE Free Pumping today.
Free Pump
KOBE
KOBE INC. Division of Dresser Equipment Co.
HUNTINGTON PARK, CALIFORNIA • OKLAHOMA CITY, OKLAHOMA

SMOOTHEST TEST You Ever Ran...

Hydro-Spring Tester — Patent Applied For

HALLIBURTON'S *REVOLUTIONARY*

HYDRO-SPRING TESTER

So simple to operate a "weevil" could run it. In the skilled hands of a Halliburton operator the Hydro-Spring Tester gives a perfect performance practically every time.

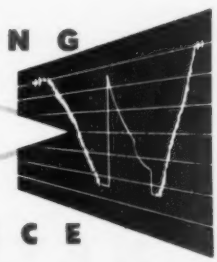
All you do is set down weight on the packer and then wait a few minutes for the tool to open. A noticeable movement on the weight indicator tells you when tool is open. Tester valve opens and closes rapidly, decreasing the time for any fluid cutting that would be caused by "half-open" valves.

If a bridge is encountered going in hole you can set down weight up to 200,000 pounds – even spud if desired – just so long as weight is removed every minute or so. Hydro-Spring Tester does not open until at the end of the maximum time delay.

The locked open by-pass operates positively in relation to the tester valve. When Hydro-Spring is closed the by-pass is open; and when the tester is opened the by-pass is closed. Operation is such that the by-pass closes an instant before the tester valve opens.

What could be simpler? No wonder Hydro-Spring makes history for the smoothest test ever run. Have you made the swing to Hydro-Spring? It'll save you time, trouble, money. Try it next – just phone your local or district Halliburton office. Or contact Halliburton Oil Well Cementing Company, Duncan, Oklahoma.

TESTING
HALLIBURTON
SERVICE



HALLIBURTON'S BEST FOR YOUR DRILL STEM TEST!

ARMCO

Spiral Welded Casing

Seven carloads of Armco Casing delivered to a major oil company in Texas.

NOW IN STOCK AT THE FOLLOWING NATIONAL TANK COMPANY BRANCHES:

Abilene, Texas
Casper, Wyo.
Clay City, Ill.
Electra, Texas
Great Bend, Kan.
Hobbs, New Mexico
Houston, Texas
Lake Charles, La.
New Iberia, La.
Odessa, Texas
Oklahoma City, Okla.
Pampa, Texas
Corpus Christi, Texas
Seminole, Okla.
Shreveport, La.
Sidney, Neb.
Williston, N. D.
Edmonton, Alberta

- EXACT 40' LENGTHS
- HIGH COLLAPSE RESISTANCE
- UNIFORM WALL THICKNESS
- FAST RUNNING TIME
- SAVES TONNAGE
- SAVES MONEY

STOCKS CARRIED AT MILL READY FOR IMMEDIATE CARLOAD SHIPMENTS.

Distributed exclusively in U.S. and Canada by National Tank Company

Manufactured by Armco Drainage & Metal Products, Inc.

It's National

NATIONAL TANK COMPANY

TULSA, OKLAHOMA

AIME

PETROLEUM TRANSACTIONS

DEVELOPMENT of an UNDERGROUND HEAT WAVE for OIL RECOVERY

BRUCE F. GRANT
STEFAN E. SZASZ
MEMBERS AIME

SINCLAIR RESEARCH LABORATORIES, INC.
TULSA, OKLA.

T. P. 3797

INTRODUCTION

During 1947, a Sinclair research team was assigned to investigate thermal methods of oil recovery. The assignment was recommended by a survey of possible research approaches to increase the amount of oil that ultimately can be recovered from oil producing reservoirs. The use of heat to stimulate oil production rates by the melting of paraffin deposited in well bores can be traced back to within one or two decades of the drilling of the Drake well.

The application of heat on a larger scale has been discussed by generations of oil producers. Shortly after the turn of the century, one intrepid operator is reported to have injected steam into a Pennsylvania property. After a few weeks, he apparently became discouraged and terminated his experiment. Subsequently, the literature contains references to several well-developed techniques for supplying heat to a producing well bore to melt paraffin or to reduce the viscosity of oil contained in the formation immediately around the well bore.[1,2,3,4] Some early references discuss procedures to furnish heat to the reservoir,[5,6] with the injection well as the heat source, thus obligating the process to maintain the entire rock mass at a temperature above that at which the desired improvement in oil recovery would occur.

Another approach to reservoir heating was reported by a group of Russian technologists in 1935.[7,8,9] They definitely demonstrated that combustion can occur within the porous structure of an oil-bearing sandstone. Their field experiments, however, relied less on combustion within the rock than on heat furnished by combustion of oil supplied to the injection well bore. Ignition of the air-oil mixtures in the well bore was found very difficult, and the field tests were carried on for only short periods of time. Publication of the Russian work spurred at least one independent operator in this country to try firing an air-gas injection well. on for only short periods of time.

Publication of the Russian work spurred at least one independent operator in this country to try firing an air-gas injection well. The Brundred Oil Corp. reportedly obtained combustion in the sand immediately around the injection well bore, but the experiment was abandoned because of interference with normal production schedules. Injection capacity of the experimental well was greatly reduced by firing. The well was reshot and pieces of sand showing partial fusing of the quartz matrix were recovered.

To the authors' knowledge no other field experiments utilizing combustion techniques for formation heating were undertaken prior to 1948, although the patent literature evidences continued interest in formation heating.[10,11]

CONCEPT OF COMBUSTION-SUPPORTED HEAT WAVE

The references cited were in agreement that heat applied to a reservoir would increase recovery, but there

[1]References given at end of paper.

Manuscript received in Petroleum Branch office Jan. 11, 1954. Paper presented at the AIME Annual Meeting in New York, N. Y., Feb. 13-17, 1954.

Discussion of this and all following technical papers is invited. Discussion in writing (3 copies) may be sent to the offices of the Journal of Petroleum Technology. Any discussion offered after Dec. 31, 1954, should be in the form of a new paper.

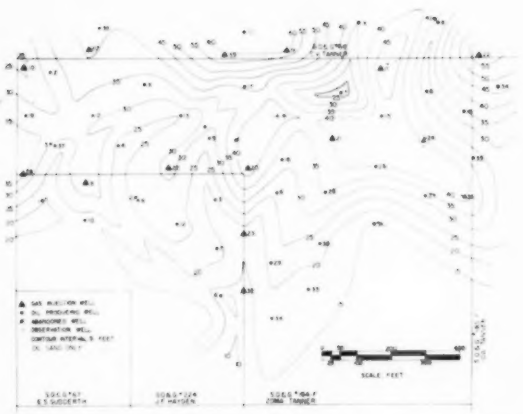


FIG. 1 — ISOPACHOUS MAP OF ZOMA TANNER PROPERTY, DELAWARE CHILDERS FIELD, NOWATA COUNTY, OKLA.

were few data as to the mechanism of the improvement or the temperature level required. The Sinclair team conducted exploratory work in the laboratory by subjecting groups of oil-saturated core samples separately to water (steam), nitrogen, and air drives over a range of temperatures up to 1,500°F. From these tests, the general conclusion was reached that temperatures of at least 700°F were necessary to approach maximum possible oil recovery. It was concluded that combustion techniques would be necessary to maintain temperatures of this magnitude. Yet, maintenance of high temperatures over the area that would be included within any reasonable well spacing was out of the question because of expected heat losses and fuel requirements.

Consideration of these factors led to the concept developed by Smith and Watson.[12] They proposed the creation of a high temperature zone in the reservoir rock around an injection well and the subsequent injection of cold gas to move the zone radially outward as a combustion-supported heat wave. Sensible heat of the rock behind the wave thus would be continually recovered and utilized to help heat "new" rock ahead of the wave. By keeping the width of the "hot" zone narrow, heat losses and fuel requirements would be minimized.

Laboratory experiments were conducted with sand packed columns saturated with crude oil and brine to develop techniques of propagating and controlling combustion and heat transfer waves. Details of some of the experiments have been given by Smith and Watson. After establishing the basic characteristics of heat wave propagation, calculations were made of the probable economic limits of the process. It was apparent that the use of air as the sole injection medium would require so great an energy consumption for compression to injection pressures as to limit commercial application to reservoirs having oil contents on the order of 1,200 bbls/acre-ft.

On the other hand, if oxygen requirements are held between 1.33 and 6.0 volume per cent, so that produced or "recycle" gas supplies 70 to 90 per cent of the total gas requirements, then compression costs of the process can be reduced in proportion to the pressure under which the produced gas can be delivered to the compressor. For example, if a 300 psi back pressure could be maintained in a field where 500 psi injection pressures were required, assuming well depths of 1,000 ft, 2½-acre five-spot development and permeability high enough to inject 250 MCF per well day, the process could be profitable with reservoir oil contents on the order of 250 bbls/acre-ft. A thermal recovery of 80 per cent of the oil in place is assumed.

Maintenance of high pressures on producing wells almost certainly would require unitized operation of pressure-depleted fields.

FIELD EXPERIMENTS (1948-1951)

EXPERIMENTAL SITE

Early in 1948, it was decided that a field trial would be necessary to determine whether a combustion-supported heat wave could be started and maintained in a reservoir. Since a shallow unitized field was not readily available for the experimental work, the decision was made to proceed on any suitable property producing a "typical" crude from shallow depths. The purpose of the initial field tests would be to develop techniques for operating subsequent experiments aimed at commercial evaluation of the process.

Through the cooperation of Sinclair Oil & Gas Co., an experimental site was secured on the 80-acre Zoma Tanner farm, located in the NE/4 NW/4, Section 1, Township 26 North, Range 16 East, close to the south edge of the extreme eastern portion of the Delaware-Childers field, Nowata County, Okla. A 35° - 37° API crude oil is produced from the Bartlesville sandstone, which occurs at a depth of 600-620 ft over the experimental area. The geology, development, and oil production history of the eastern portion of the Delaware-Childers field has been comprehensively studied by Johnston and Riggs.[13]

Fig. 1 is a map of the Zoma Tanner property, with contours of oil-sand thickness, as taken from drillers' logs. Only the lower portion of the Bartlesville sand is oil saturated. The upper section is logged as "gas" sand. The 15-ft contour has been taken to be the edge of the productive area, as data from adjoining leases indicate the sand body thins abruptly along this line. The original development occurred between 1908

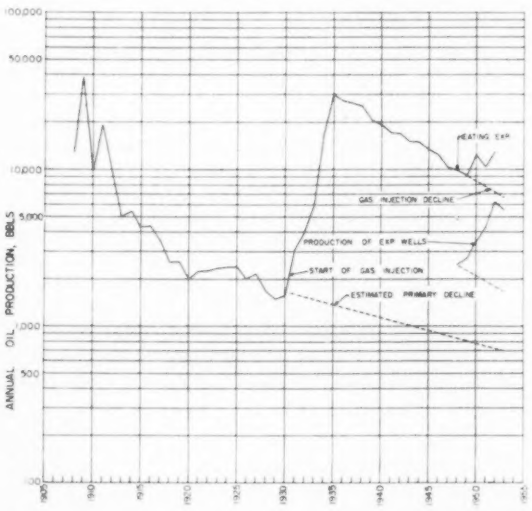


FIG. 2 — OIL PRODUCTION HISTORY OF ZOMA TANNER PROPERTY.

and 1912 when nine wells were drilled, eight of which were still producing in 1934 when gas injection was started on the property. Ten injection and 16 producing wells were drilled during the period from 1935-1938 to complete the secondary development. One producing well was converted to injection service in 1939. The oil production history of the property is presented in Fig. 2, and the effect of gas injected into adjoining leases is evident beginning in 1931. Reservoir and recovery data are tabulated below:

Production area, acres	60
Volume of oil productive sand, acre feet	1,893
Average permeability, md	145
Average porosity, percent	19.3
Assumed interstitial water content, percent of pore space	35
Assumed reservoir oil shrinkage, per cent	10.5
Calculated initial oil content, stock tank barrels	1,667,281
Primary production, 1908-1930 (inclusive), barrels	140,291
Primary production, percent of original oil	8.4
Production by gas injection, 1931-1947 (inclusive) barrels	277,103
Production by gas injection, per cent of original oil	16.6
Cumulative oil produced, 1908-1947 (inclusive), barrels	417,394
Cumulative oil produced, percent of original oil	25.0
Calculated oil content at end of 1947, barrels per acre-foot	660

Volumes of gas injected during the period 1934 to 1948 are not readily available. In general, injection rates were held to 15,000 cu ft per well per day. Daily oil production rates during June, 1948, averaged 1.1 bbl per well at an average estimated injected gas-oil ratio of 6,450 cu ft/bbl. No connate water has ever been produced with the oil in this portion of the field.

Preparation of Well 35

The first field experiments with thermal recovery were designed to develop techniques of "firing" a well, an operation which includes two separate steps: (1) burning fuel within the well bore to heat the sand around the well to temperatures sufficiently high to permit, (2) transferring combustion to the porous structure of the sand.

Injection well 35 on the Zoma Tanner lease was selected for these tests. The well had been completed as a producing well in 1937. The Bartlesville sand was logged in the depth interval 587 to 633 ft. The oil pay between 592 and 633 ft had been shot with 60 quarts of nitroglycerine. The well had been converted to injection service in 1949. In preparation for the tests, a bridge was placed at the top of the oil sand and the casing lowered by underreaming to this point, cemented, and the hole cleaned. Injection capacity of the well after cleaning was 310 MCF daily at 150 psi. The rig then was used to drill an observation well 20 ft west of well 35. The observation well was equipped with tubing set on a packer at the top of the oil sand. The annulus above the packer was loaded with mud. A thermocouple in a sealed quarter-inch thermowell was run inside the tubing string to a point below the packer.

For the first step of the firing procedure, a burner designed by Piros was installed in well 35. Although several types of well-bore burners were available, none of these completely fulfilled the postulated requirements for a well-bore burner which would operate with gaseous fuels under injection pressures up to 500 psi at heat release rates up to 500,000 Btu hourly with provision for wellhead control of burner ignition and of final combustion temperatures. Construction of the burner is shown in Fig. 3. Gas is injected through a ½-in. line, primary air through a concentric string of 2-in. tubing, and secondary air through the annulus between tubing and casing. The burner was placed at

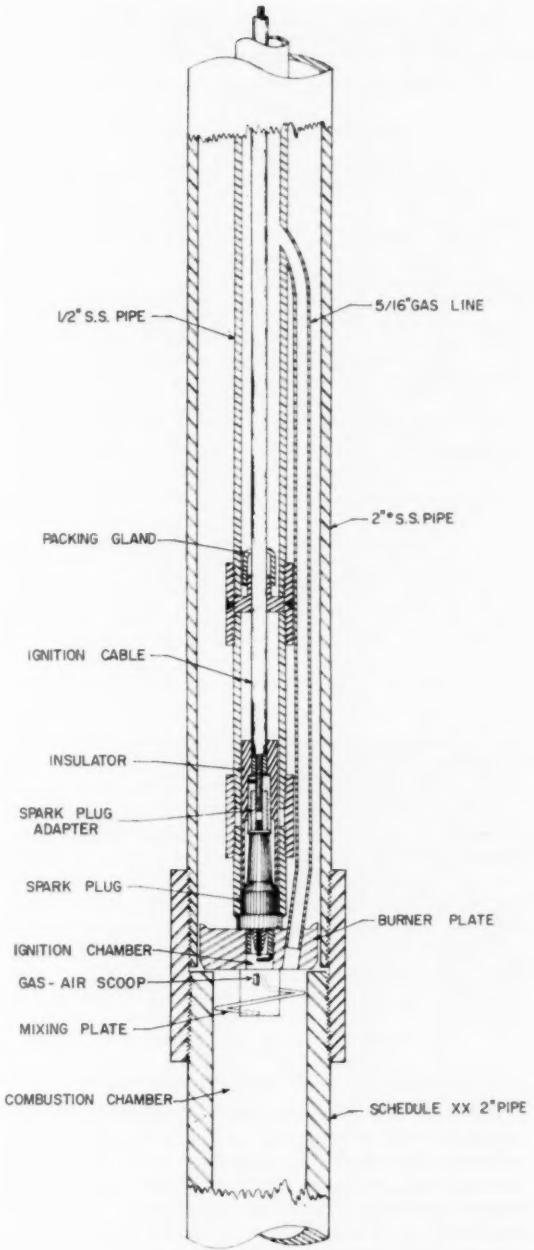


Fig. 3 — Piros Burner.

a depth of 600 ft so as not to injure the casing or impair the cement job around the casing shoe, and the hole was pressured with air in order to drive water and moisture from the well bore. Then, metered quantities of gas and primary and secondary air were injected, and the mixture was lighted by a high tension spark plug. As soon as the thermocouple below the tip of the burner indicated a rise in temperature, gas and air rates were adjusted to give maximum hourly heat release rates with flue gas temperatures between 1,200°F and 1,800°F under an operating pressure of 500 psi.

The step of transferring combustion to the heated

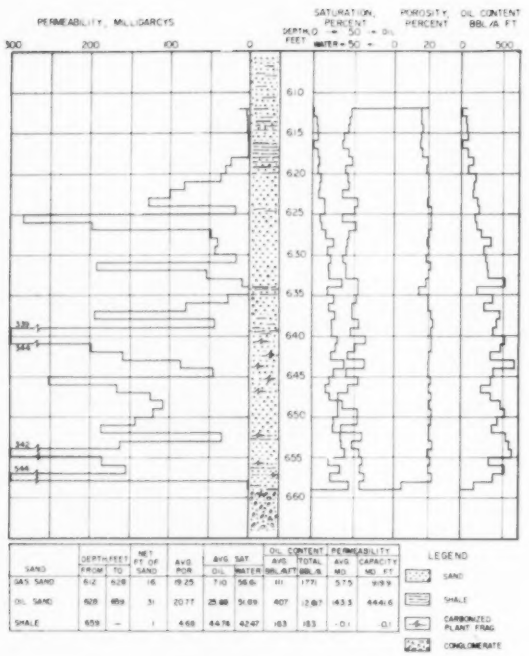


FIG. 4 — CORE DATA, WELL 24-WEST.

sand immediately around the injection well bore was not difficult to accomplish provided the burner had been operated to transfer at least 50 million Btu to the 51-ft-thick sand. Several transfer techniques were used successfully, but all involved the injection of non-combustible gases. The simplest method was to shut off the fuel gas supply and to inject air alone. Injection well sand face temperature dropped sharply, but burning continued out into the formation as evidenced by the continuing presence of carbon dioxide in the gas produced from the observation well. The residual oil content of the formation supplied the necessary fuel during this step.

PROPAGATION OF HEAT WAVE INTO FORMATION

The next phase of the field experimentation was concerned with propagation of the combustion wave outward from well 35. The degree of combustion obtained with any given mixture of gases injected into well 35 was judged by the oxygen and carbon dioxide content of gas produced from the observation well and from the nearby producing wells. The limiting amounts of any one component of the mixture (air, recycle gas, or fuel gas) were explored by continuously varying the proportion of the component even to the point of losing combustion. These experiments confirmed the expected dependence of propagation rates on the oxygen-fuel ratio of the injected gases. For example, a mixture of air and produced gas having a hydrocarbon content equivalent to 80 Btu/cu ft and containing 6 per cent of oxygen caused the combustion to move from the injection to the observation well at a more rapid rate than was observed with any other mixture injected. However, as the oxygen content was increased beyond 6 per cent, forward travel of the combustion slowed; when the oxygen content of the injected gas (hydrocarbon content of 80 Btu) reached 12 per cent, the burning "flashed back" to the injection well bore. In subsequent tests, each time the proportions of oxygen to hydrocarbon came within the explosive range, as defined by Jones,[15] the combustion burned back toward the injection well.

In later experiments, it was found possible to get a "rich" mixture into the combustion zone by injecting alternate slugs of air and fuel without incurring excessive broadening of the zone through "burn-back." The amounts of each gas were proportioned to approach the stoichiometric proportions for complete combustion, while the volumes and timing of the separate injection cycles were adjusted to prevent complete mixing until the gases entered the combustion zone.

All of the experimental work at well 35 was aimed at developing operating methods which later could be utilized in a long-term test. The development of the fuel injection techniques was considered particularly necessary because with the injection of air alone to propagate the combustion wave, oxygen contents of gas produced from wells ahead of the wave had not been less than 5 per cent and had shown a tendency to increase with continued air injection. The same phenomenon had been observed in laboratory tests and was invariably associated with a decline in peak temperature of the wave. Thus, it was felt that long-term operation with air injection could eventually extinguish combustion unless reliable techniques were developed for revivifying the combustion wave.

EXPERIMENTS WITH WELL 24 (1949-1953)

PRELIMINARY WORK

By 1949, the encouraging aspects of tests at well 35 led to a decision to prepare a well pattern for an extended test. Injection well 24 on the same lease was selected. An inverted seven-spot pattern is formed by well 24 and the six offset producing wells with an average distance of 300 ft from injection to producing wells. Well 24 had been drilled in 1934 and had been shot upon completion. Casing had been set at the top of

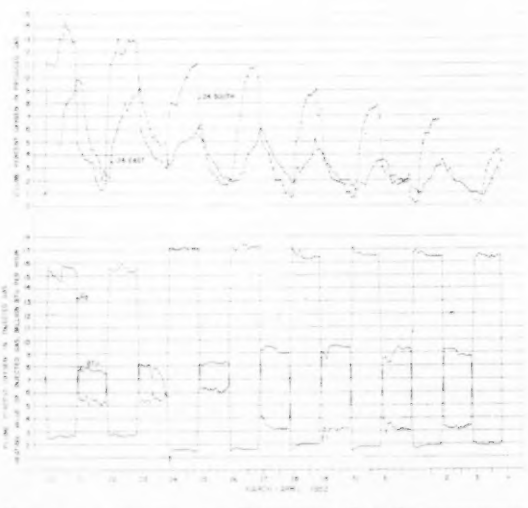


FIG. 5 — INJECTED AND PRODUCED GAS COMPOSITIONS DURING CYCLIC OPERATION TO FORM HEAT WAVE AT WELL 24-WEST.

the sand at a depth of 617 ft. In preparation for the tests, the well was cleaned, but not reshot. The casing point was not changed. After cleaning, air was injected into the well at a rate of 480 MCF daily at a pressure of 380 psi.

Four observation wells designated as 24-West, 24-North, 24-East, and 24-South were drilled as shown in Fig. 1, placing them on the corners of a square, 37.5 ft apart and 26.5 ft from well 24; they were cored using fresh water as the drilling fluid. Analysis showed the cores to be practically identical; the coregraph for well 24W is given in Fig. 4. In spite of an average dry air permeability of 140 md shown by the cores, none of the wells ever produced more than 15 per cent of the gas injected into well 24. Total oil production of the four wells was less than 1 bbl weekly, with 5 to 10 bbls of water. The low oil content of 407 bbls/acre-ft shown by the cores, and the low oil production are probably attributable to the close proximity of an operating gas injection well. Moreover, subsequent experience has shown that the fresh water used in coring severely impairs the ability of the cored well to produce gas on oil in this field.

Other preparatory work included rearranging gas and oil gathering lines to separate the six offset producing wells from the lease system. Gas sampling and metering connections were provided for the observation and producing wells. Thermowells were installed in the observation well.

A Piros burner was installed in the injection well and the burner was ignited on June 14, 1949. Injection pressures were much higher than indicated by the flow test. Combustion was transferred to the sand July 1, but pressures increased until on September 26, the test was discontinued. The well was opened and found to be filled with loose sand. Extensive cleaning was required, and the well was recased. On October 6, the burner was relighted, but after eight days of operation, the well bore became plugged. In the next two months, three successive cave-ins prevented continuous operation of the burner. On Jan. 11, 1950, the burner was lighted. After two weeks, combustion was transferred to the formation and operations continued until March 9, when the fire flashed back to the injection well bore as a result of attempts to inject mixtures in the explosive range. A hole was burned in the casing and the well was abandoned.

A replacement well drilled 6 ft southwest of well 24 was designated well 36. After completion, a mixture of air and produced gas having 6 per cent oxygen content was injected without any ignition device in the well. Immediate combustion occurred in the formation, as evidenced by the disappearance of oxygen from the produced gas. After 30 days of operation, injection pressure increased and it was decided to switch to straight air injection; however, only 12 hours after the switch, an explosion occurred in the well, collapsing the casing and causing the well to be abandoned.

Consequently, well 24W was prepared for injection, and recompleted by cementing the 53/16-in. casing at 617 ft and reaming the core hole to 5-in. diameter. An injection profile obtained with a spinner showed most of the injected gas to be entering the "gas sand" in the upper part of the sand. The depth interval from 617 to 628 ft was squeezed with 25 sacks of cement and the hole redrilled to a depth of 655 ft. From a second spinner survey, it was found that at injection rates below 250 MCF daily, by-passing to the upper sand still was evident; however, at rates of 500 MCF daily, the injected gas was uniformly distributed over the sand face. As operation would be at the higher rate, the completion was considered satisfactory.

Firing and Operation of 24-West Well

Although the remedial work was completed in April, 1951, firing of the well was delayed until the completion of the tests at well 35. On Dec. 27, 1951, well 24W was fired. The burner was operated until January 13, when the well was opened to clear an obstruction between the casing and 2-in. tubing which interfered with the flow of secondary air to the burner. On removing the burner, it was found that the mixing plate and combustion chamber had burned off. The well was cleaned, re-equipped, and the burner lighted on Jan. 23, 1952. Operation was continued with combustion in the well bore regulated to hold a temperature of 1,000°F at a point 6 in. below the burner outlet. By February 5, samples from observation wells contained less oxygen than the flue gas being injected, thus confirming that combustion was occurring in the formation.

Rather than drive the combustion away from the well bore, mixtures which would burn at well bore temperatures (1,000-1,200°F) were injected at the maximum possible rate to maintain combustion in and around the well bore. This operation was continued until March 20, when the injection of high air-fuel ratio mixtures for 24 hours was alternated with the injection of low ratio mixtures for 24 hours. In Fig. 5 are plotted the oxygen contents of injected gas during these cycles and of gas from East and South wells. Progressive smoothing of these latter curves occurred as combustion moved to, and became stable at, the forward edge of the heated area. The injection program of alternate days on high oxygen content gas was continued until April 9. At that time, the average oxygen content of gas produced from the six producing wells was 2 per cent. The injection well bore temperature had dropped from 1,000°F at the start of cyclic injection to 190°F on April 9. On this date, the continuous injection was started of an air-produced gas mixture containing 16 per cent oxygen and hydrocarbons equivalent to 40 Btu/cu ft. The subsequent changes in injection are summarized in Table 1, which also gives the quantities of gas, oxygen, and hydrocarbons injected to Nov. 28, 1953.

The columns in Table 1 which list the estimated oxygen consumed and the total heat generated were computed. At any given time, the weighted average oxygen content of the gas produced at the six "inner ring" producing wells (Wells 27, 25, 15, 8, and 16 on the Zoma Tanner, and well 35 on the Ida Tanner lease) was considered to represent the unburned portion of the oxygen injected during that time. It is realized that this assumption does not take into account the time delay between the injection and production of a unit volume of gas. The travel time, apparently, does not exceed two days to any of the wells and the time for a change in the combustion reaction to be reflected at the producing wells ranges up to a week. Considering the length of the test period, the simplification on a daily basis probably introduces only a negligible error in the estimate of total oxygen consumed. The quantity of heat generated was computed by assuming 500 Btu to be released for each standard cubic foot of oxygen consumed.

TABLE 1 — SUMMARY OF INJECTION TO SEVEN SPOT WELL PATTERN

Interval From	Interval To	Injection Mixture	Oxygen Content Percent	Heating Value Btu/CF	Approximate Injection rate MCFH	Time Interval Days	Gas Injected MCF	Oxygen Injected MCF	Fuel Injected Btu x 10^9
12-27-51	1-13-52	Air, nat. gas and prod. gas*	11	152	20	18	8,850	960.4	1,345.3
1-13-52	1-23-52	Shut down	0	0	0	10	0	0	0
1-23-52	2- 5-52	Air, nat. gas and prod. gas*	7	156	20	13	6,118	445.5	954.1
2- 5-52	3-20-52	Air and prod. gas**	9.5	135	40	44	43,562	4,043.5	5,893.8
3-20-52	4 -9-52	Air and prod. gas alternately	10	119	45	20	22,025	2,239.6	2,612.0
4- 9-52	4-13-52	Air and prod. gas	16	43	50	4	4,753	769.4	202.3
4-13-52	4-16-52	Air and prod. gas	17	34	50	3	3,537	603.9	119.2
4-16-52	7- 7-52	Air and prod. gas	16.5	42	47	82	93,449	15,598.6	3,888.1
7- 7-52	7-17-52	Air and prod. gas	17.5	28	45	10	10,724	1,885.6	303.4
7-17-52	10- 6-52	Air and prod. gas	18	21	40	81	76,945	14,734.1	1,611.6
10- 6-52	11- 5-52	Air	21	8	36	30	24,889	5,175.2	19.0
11- 5-52	11-18-52	Air and prod. gas	18	24	42	13	10,470	2,454.9	250.3
11-18-52	1- 5-53	Shut down	0	0	0	48	0	0	0
1- 5-53	1-12-53	Air and prod. gas	17	38	33	7	4,210	733.6	158.9
1-12-53	1-23-53	Air and nat. gas	20	10	24	11	6,725	1,294.0	66.4
1-23-53	3- 3-53	Air and nat. gas†	20.8	7	45	39	33,147	7,611.8	230.8
3- 3-53	4-28-53	Air and nat. gas	20.9	5	47	56	59,320	12,052.2	315.7
4-28-53	5-22-53	Air	21	0	47	24	26,357	5,543.7	0
5-22-53	6-14-53	Air and nat. gas	20.9	5	47	23	23,578	4,954.7	116.2
6-14-53	8-18-53	Air and nat. gas	20.9	5	32	65	45,212	9,480.5	242.2
8-18-53	11- 1-53	Air	21	5	30	75	50,667	10,597	0
11- 1-53	11-28-53	Air and nat. gas	20.5	17	30	27	19,829	4,153.6	333.3
			18.3	33		703	574,367	105,351.8	18,662.6

*Burner in operation
**Burner off, combustion in well bore and formation
†Injection changed from 24W to 24WA

The rates of oxygen injection and consumption are shown in Fig. 6 on a weekly basis. The cumulative heat generated by the oxygen consumed is plotted in Fig. 7 together with the Btu equivalent of all hydrocarbon gases injected.

Progress of Formation Heating

From June 14, 1949, to Mar. 11, 1950, well 24 was fired for only 173 days. North well was the first to show results: by December, 1949, its bottom-hole temperature had increased to 200°F, and the quantity of water produced by this well since its completion, increased with the bottom-hole temperature. In the spring of 1950, the following production sequence occurred: (1) a tight emulsion was produced for several weeks, followed by (2) the production of 40 bbls of 45° API distillate with less than normal amount of water, then, (3) production of a mixture of water and colloidal iron oxide having the appearance of thin red barn paint, and finally (4) a five-fold increase in gas production rate and the production of clear water with a trace of black residual oil having a gravity of 30° API. The corrosion of well bore equipment during stages (2) and (3) were so severe that plain steel tubing and thermowells were replaced at intervals as short as two weeks. In May, 1950, the lower joint of casing was corroded through. After installing a thermowell and gas sample line, the hole was bridged at the top of the sand and cemented.

By August, 1950, when experiments were discontinued on well 36, temperatures were as follows:

North well, 230°F; East well, 145°F; South well, 120°F; and West well, 180°F.

Sixteen months later, when injection in this area was resumed using West well, temperatures were as follows:

North well, 150°F; East well, 95°F; and South well, 95°F.

Formation temperatures 300 ft distant at the inner ring producing wells were unchanged from the normal 75°F. When South well temperatures reached 250°F in October, 1952, the same production sequence started as was observed when the heat wave reached the vicinity of North well. The "barn paint" stage was reached by South well in December, 1952, after 10 bbls of 42° API oil had been flowed from the well. Failure of the thermowell prevented measurement of well bore temperatures during this period. During January, 1953, the production of live steam from the well prevented repair work so the well was filled with mud. It is assumed that the combustion front then had passed the location of South well.

The same sequence of events occurred in East Well 24 weeks later than at South, leading to the assumption that the combustion front had passed the location of East well by July, 1953.

On Dec. 14, 1952, a cable-tool drilling rig was moved to a location designated as 24WA, 50 ft from West well in the direction of well 25. After cementing casing at 614.5 ft, a rotary coring rig was moved in and the hole cored from a depth of 601 ft (top of cement plug) to a depth of 670 ft. Air was used as the circulating medium to a depth of 654.5 ft, and coring was completed with water as the circulating medium. No trace of oil was visible on the pits during the entire coring operation. The location of the well obviously was behind the combustion front. All recovered core samples of the "oil" sand were red-brown in appearance. Clay inclusions, normally gray in color, were burned brick red. This was also true of the more

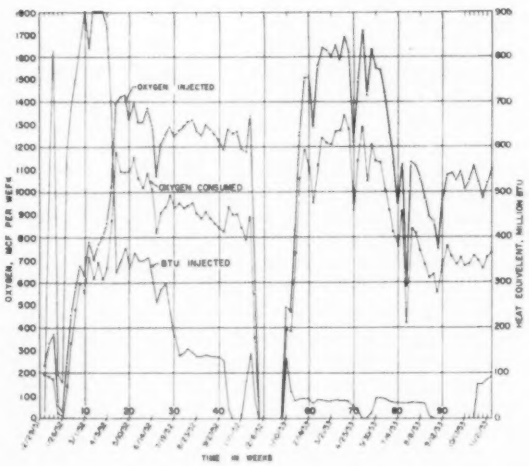


FIG. 6 — WEEKLY RATE OF OXYGEN INJECTED AND CONSUMED.

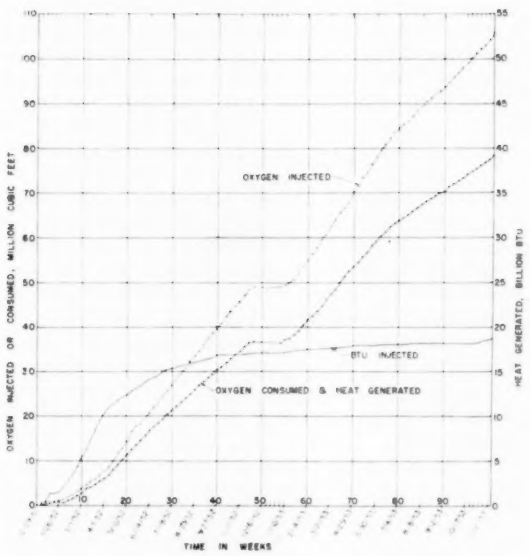


FIG. 7 — CUMULATIVE OXYGEN INJECTED AND HEAT GENERATED.

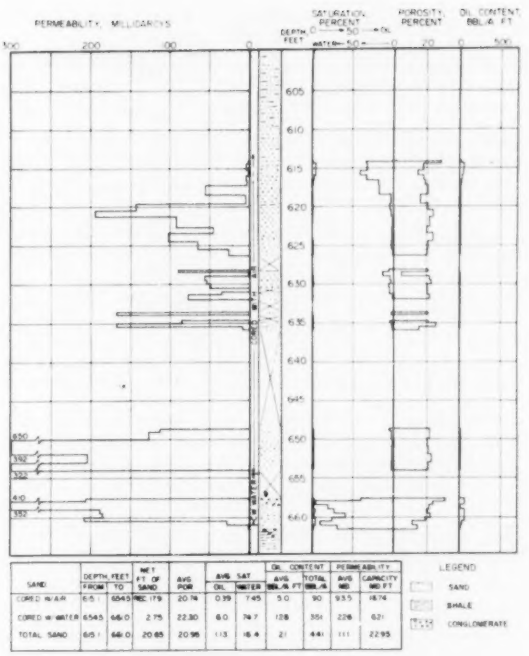


FIG. 8 — CORE DATA, WELL 24WA.

permeable beds of the "gas" sand. The coregraph of this well is plotted in Fig. 8.

Six other exploratory wells were drilled to define the extent of the heated area. Their locations are shown on Fig. 9. Core data are summarized in Table 2. The locations of wells 24WC and 24WG proved to be behind the combustion front in the trailing edge of the heat wave. The other four wells were drilled ahead of the heat wave. To illustrate the liquid contents ahead of the wave, the coregraph of well 24WB is shown on Fig. 10. By Dec. 1, 1953, well 24WD was producing in the "barn paint" stage and the combustion front was assumed to be at the location of this well and within a few feet of well 24WB. Well 24NA temperatures did not start to increase until January, 1954, and the assumption has been made that this well was located the same distance in front of the wave as was 24WB at the time it was drilled.

The outline of the area traversed by the heat wave to Dec. 1, 1953, is drawn on Fig. 9. The outline includes 0.92 acres and approximates an ellipse in shape. The major axis of the ellipse is along the line between wells 24W and 24WB with the center between wells 24W and 24WA.

EFFECT OF HEAT WAVE ON OIL PRODUCTION

The injection of gas at the relatively high rates (200 MCFD to 1,200 MCFD) required by the combustion experiments affected the oil production rates of the Zoma Tanner property and of each offsetting property. Fig. 2 is a plot of the annual oil production rates of the Zoma Tanner property. An extrapolation by the method of least squares of the exponential decline in production rate from 1938 to 1948 was used as the basis for computing an increased recovery of 16,563 bbls as a result of the experimental work. Similarly, in the period 1948-1953, 10,539 bbls have been gained on the Clyde Tanner property to the North; 3,445 bbls from the Ida Tanner property to the East; and 4,424 bbls from the J. F. Hayden property to the West. Total increased recovery is estimated at 34,971 bbls of oil.

Also plotted on Fig. 2 are the annual oil productions of the six producing wells in the experimental area. Based on the short period prior to the experiment during which the six wells were separately gaged, the 1948 production of the group would not have been more than 2,580 bbls. Extrapolating from this point by using the same percentage decline trend exhibited by the lease as a whole leads to the conclusion that 11,106 bbls or 67 per cent of the oil gained on the Zoma Tanner property have come from the six inner ring wells.

An accurate evaluation of the oil recovered that is directly attributable to the combustion-supported heat wave has not been made for the following reasons:

1. From the weekly rates of gas injected and produced within the pattern during 1952 and 1953, plotted in Fig. 11, it will be noted that the produced gas represents only 60 to 65 per cent of the injected gas. This is

TABLE 2 – SUMMARY OF OBSERVATION WELL DATA

Well	Date Coring Completed	Distance and Direction from West, ft	Coring Fluid	CORE DATA: Gas Sand Thickness ft	Gas Sand Porosity per cent	Gas Sand Permeability md	Gas Sand Oil Content bbl/acre ft	Oil Sand Thickness ft	Oil Sand Porosity per cent	Oil Sand Permeability md	Oil Sand Oil Content bbl/acre ft	Max. Temp. When Drilled °F	Temp. Dec. 1, 1953 °F
24WB	3- 3-53	170 SW	Air	25.15	17.0	51	56	29.7	21.2	160	524	78	200
24WC	4-27-53	100 SW	Air	20.9	20.9	97	25	24.1	23.0	211	8	650	340
24WD	7-24-53	100 NW	Water	14	18.2	50	102	35	21.0	147	464	140	235
24NA	7-15-53	125 NE	Water	17	16.6	98	84	20	19.9	101	562	78	78
24SA	2- 8-54	108 S SE	Water	19	19.3	125	149	23	21.1	179	499	90	
24WG	2-11-54	83 S	Water	29	18.7	73	10.5	24.1	20.4	233	6	530	

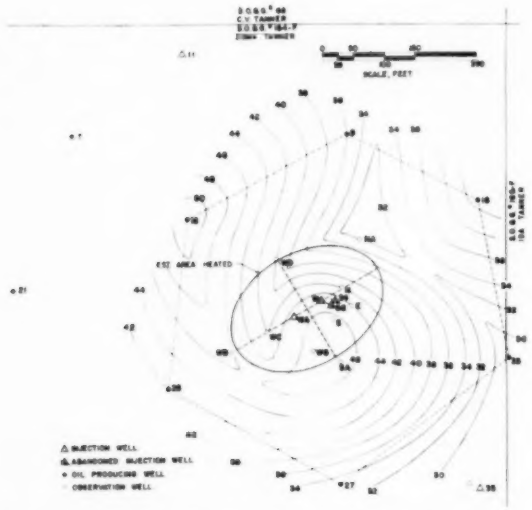


FIG. 9 — EXPERIMENTAL WELL PATTERN WITH OBSERVATION WELL LOCATIONS AND THICKNESS CONTOURS OF GROSS PERMEABLE SAND.

due, no doubt, to the fact that only a small amount of gas was injected outside the pattern, and, therefore, some gas injected within the pattern has found its way between the inner ring wells into the area outside the pattern. A similar phenomenon is to be expected for any oil which is moved.

2. Although gas was injected into all of the permeable formation, oil may have been moved and produced only from the oil sand and not from the upper gas sand.

3. The heat wave was reached only a relatively small portion of the pattern area. The oil removed from the sand behind the heat wave may have been recovered from the inner ring wells, driven out of the pattern area between the producing wells, burned, and/or stored within the pattern ahead of the heat wave as an increased oil content of the formation.

However, there are two encouraging factors at present which indicate that oil has been moved:

1. From the gas/oil ratios of the pattern wells plotted in Fig. 12, it is apparent that the upward trend in evidence during 1952 has been reversed during the last half of 1953. This probably reflects an increased oil content over the unheated area of the pattern, thereby changing the oil-gas relative permeability.

2. From the data shown below:

	Pattern Area	Heated Area
Surface area, acres	5.2	0.92
Net permeable sand, acre-feet	208.0	39.3
Oil containing sand, acre-feet	145.2	28.1
Average porosity, per cent	20.9	20.9
Estimated oil content, as of Dec. 31, 1951, based on 660 bbls/acre-ft oil content on Jan. 1, 1948; bbl	73,822	13,930
Oil produced, January, 1952-December, 1953; bbl	10 549	

The average oil content of the oil sand in the pattern area as of Jan. 1, 1952, was 509 bbl/acre-ft. However, the coregraphs of well 24WB (Fig. 10) and well 24NA show average oil contents of 524 and 562 bbls/acre-ft in spite of the fact that some oil has been produced between Jan. 1, 1952, and the time these wells were drilled. If the difference between the oil content of the pattern as of Jan. 1, 1952, and the oil produced in the 101 weeks of the experiment is considered distributed only over the unheated pattern area, the oil content would be 541 bbls/acre-ft, in good agreement with the data obtained from the two observation wells.

DISCUSSION OF THE HEAT WAVE

The basic facts about the generation and propogation of a combustion-supported heat wave through the formation are pretty well understood, and some experimental data have been derived from the field tests described in this paper. The well established facts may be summarized as follows:

1. There is a heat wave in the formation, in the sense that a high temperature zone moves outward from the injection well, with substantially lower temperatures prevailing in front as well as behind the high temperature zone.

2. The formation behind the high temperature zone has been practically stripped of its original oil content.

3. The peak temperature of the wave must have been slightiy over 1,000°F throughout the permeable part of the formation and about 700°F in a shaly section separating the oil sand from the gas sand. This was established by microscopic examination of grains of ankerite in thin sections made from cores from wells 24WA and 24WC, and by comparison with grains of the same mineral in samples from well 24WB which had been subjected to controlled heating conditions in the laboratory.

4. Combustion is actually taking place in the formation, as evidenced by the low oxygen and high carbon dioxide content of the gas produced from the pattern. Whether the residual oxygen in the produced gas is due to by-passing of injected gas through the gas sand, where there is not enough residual fuel to burn all the oxygen, or to the fact that the ignition temperature

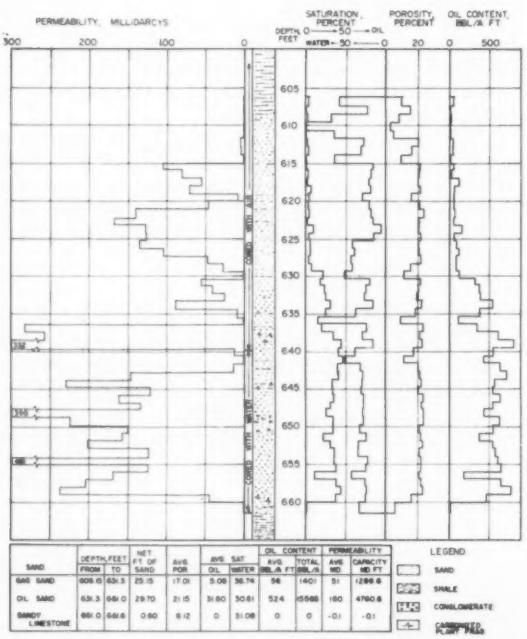


FIG. 10 — CORE DATA, WELL 24WB.

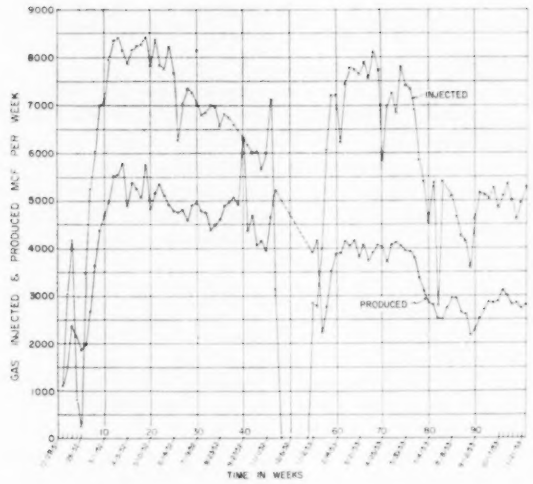


FIG. 11 — WEEKLY RATES OF GAS INJECTION AND PRODUCTION, EXPERIMENTAL WELL PATTERN.

was not reached for all components of the fuel could not be decided from these tests.

However, much detailed information is still lacking, to the point that it is not yet possible to calculate exactly what happens at every point and at every moment in the formation. The missing data concern primarily the heat exchange between the moving fluids and the stationary matrix, and the exact spot where, and extent to which, combustion in the formation occurs. Moreover, the temperature distribution along the wave is also unknown; it cannot be determined even from observation wells, because the drilling and existence of these wells distorts the wave in their vicinity. Temperatures measured in observation wells are always lower than they would be in absence of the well, because of the heat loss through the well bore.

Although heat losses to the over- and under burden are not known exactly, some indications were obtained from measuring temperature gradients just above the permeable formation when drilling wells 24WA and 24WC. The average value found was 5.17°F/ft. Assuming that heat loss to over- and under burden is a steady-state phenomenon occurring only from the heated area, and that gas injection and oxygen consumption were uniform throughout the 101-week test period, the following instantaneous heat balance can be set up:

heat generated = heat loss to over-and under burden + heat available to heat up new formation.

Using the following set of data:

- specific heat of injected gas = 0.02 Btu/scf/°F
- specific heat of matrix: 0.2 Btu/lb/°F
- density of matrix: 137 lb/cu ft
- average formation thickness: 42.7 ft
- average gas injection rate: 812 MCF/D
- average oxygen consumption rate: 111 MCF/D
- heat generated by oxygen consumption: 500 Btu/scf
- peak temperature of the wave: 1,000°F
- thermal conductivity of wet, compressed shale: 1.0 fph units

The heat loss to over- and under burden is found to be 248 Btu/sq ft/day, and the heat balance yields the differential equation.

$$55{,}500{,}000 = 248\,A + 1{,}082{,}000\,\frac{dA}{dt}$$

where A is the heated area at any time t. Integrating this equation

$$A = 224{,}000\,(1 - e^{-0.0002291\,t})$$

or, for t = 707 days, A = 33,600 sq ft. The total area swept by the heat wave, including the area cooled down by the injected gas behind the wave, is then 42,880 sq ft or 0.983 acres, in excellent agreement with the area determined experimentally. It is true that the assumptions on which these calculations were based may be optimistic, but in the authors' opinion heat losses did not have a major influence on the propagation of the heat wave during this experiment.

SUMMARY AND CONCLUDING STATEMENT

The experimental work described in this paper has demonstrated the feasibility of creating and propogating a combustion-supported heat wave through an oil-bearing reservoir rock. Reliable techniques for firing an injection well and transferring combustion to the reservoir rock have been developed. The methods used to maintain wave continuity and temperature are described. Propagation of the heat wave has been continuous for a period of time sufficent to allow the statement that no undue difficulty will be encountered in moving a wave over the areas included in ordinary secondary recovery well spacing patterns.

Although it is realized that the work done this far is not complete and that much more remains to be done in the future in order to find precise answers to engineering problems such as heat loss, temperature distribution, well spacing and heat economy, the process looks promising from the viewpoint of recovery efficiency. Two facts must be considered in this respect: First the experiments so far have demonstrated practically complete depletion of the oil-bearing formation in the heated area, a result which cannot be approached by any recovery method now in use; and, second, laboratory results indicate that the oil present in the formation with the exception of a residual of the order

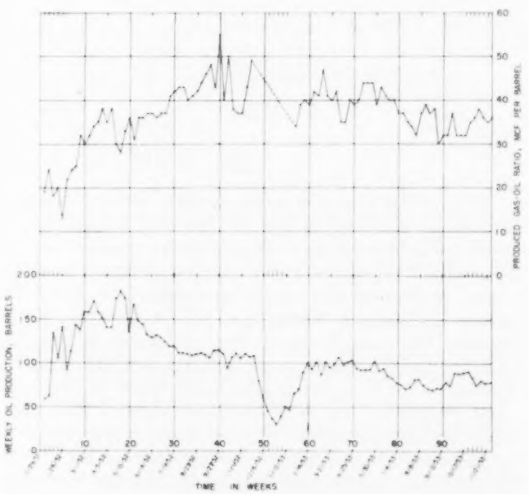


FIG. 12 — WEEKLY OIL PRODUCTION RATES AND PRODUCED GAS-OIL RATIOS, EXPERIMENTAL WELL PATTERN.

of 60 bbls/acre-ft, can be moved by the very front edge of the wave, before ignition temperatures are reached, and hence should be recoverable.

Since the experiments described in this paper were not conducted with economic efficiency in mind, it seems premature to draw conclusions as to the economic factors governing oil recovery by means of a combustion-supported heat wave. As an example, and as a subject for future study, it may be mentioned that recycling of gas produced at higher than atmospheric pressure would have a tremendous influence on the capacity of the compressor plant, and hence, through the compression costs, on the economy of the process.

ACKNOWLEDGMENTS

The authors are grateful to the managements of Sinclair Oil & Gas Co. and Sinclair Research Laboratories, Inc., for permission to publish these experimental data.

The authors wish to point out that their role is chiefly reportorial. Credit for the conception of the heat wave process and for conducting the substantiating experiments belongs to over a dozen members of the Company's Tulsa and Harvey Laboratories.

REFERENCES

1. Reistle, E. C., Jr: "Paraffin and Congealing-Oil Problems," *U. S. Bureau of Mines Bulletin 348* (1932), 89.
2. Howard, Frank A.: "Process for Distilling Crude Oil Underground," U. S. Patent 1,473,348 (Nov. 6, 1923). See also *National Petroleum News*, **16**, No. 4-5 (Feb. 27, 1954), 97.
3. "Shot Gun Shells Used in the Removal of Paraffin and Residue from Oil Wells," *The Producers Monthly*, 8 (April, 1944), 20.
4. Squires, F., and Merriam, E. S.: "A Burner for Underground Generation of Heat," *Producers Monthly*, **16** (May, 1952), 11.
5. Lindsly, B. E.: "Oil Recovery by Use of Heated Gas," *The Oil and Gas Jour.*, **27** (Dec. 20, 1928), 27.
6. Stovall, S. L.: "Recovery of Oil from Depleted Sands by Means of Dry Steam," *Oil Weekly*, **74** (Aug. 13, 1934), 17.
7. Sheinman, A. B., et al: "Gasification of Crude Oil Oil in Reservoir Sands," Neftyance Khozyaistva, **28** (April, 1935), English translation published in *Petroleum Engineer*, **10** (December, 1938) 27, and (February, 1939), 91.
8. Sheinman, A. B.: "Secondary Recovery and Underground Gasification of Oil Deposits," *Novosti Tekhniki*, **15** (1939), 30-3.
9. Lapuk, B. B.: "Heat Treatment of Oil Sands to Increase the Oil Yield," *Azerbaidzhanskoe Neftyance Khoz*, **12** (1939), 10-15.
10. Frey, F. E.: "Method of Recovery of Hydrocarbons" U. S. Patent 2382471 (Aug. 14, 1945).
11. Barton, P. D., and Dougherty, P. F.: "Method of Producing Petroleum," U. S. Patent 2390770 (Dec. 11, 1945).
12. Smith, Robert L., and Watson, Kenneth M.: "Oil Recovery Process," U. S. Patent 2642943 (June 23, 1953).
13. Johnston, Kenneth H., and Riggs, C. H.: "Secondary-Recovery Practices and Oil Reserves in the Eastern Part of the Delaware-Childers Field, Nowata County, Okla.," *U. S. Bureau of Mines Report of Investigation 4019* (December, 1946).
14. Piros, John J., et al: "Gas Burner and Method for Burning Gas in Oil and Gas Wells," U. S. Patent Application.
15. Jones, G. W., Kennedy, R. E., and Spolan, I.: "Effect of High Pressures on the Flammability of Natural Gas-Air-Nitrogen Mixtures." *U. S. Bureau of Mines Report of Investigation 4557* (November, 1949), Fig. 6.

DISCUSSION

H. J. RAMEY, JR.
JUNIOR MEMBER AIME

MAGNOLIA RESEARCH LABORATORIES
DALLAS, TEXAS

During the past few years, intense interest has been shown in the application of thermal energy to oil-bearing reservoirs as a means of increasing the percentage oil recovery. The paper by authors Grant and Szasz is another important contribution to the rather sparse literature in this field of oil recovery by thermal means. The authors have done a fine job of reporting the results from the work of the Sinclair Research Laboratories, Inc., on in-situ combustion experimentation. However, we feel that the authors have been unnecessarily restrictive in their conclusions about the appropriate composition of the injection gas stream and about some aspects of the economics of an in-situ combustion operation, particularly since their conclusions were based on only one experiment conducted under only one set of reservoir conditions. We are of the opinion that a number of field experiments must be conducted in different types of oil sands and under a variety of conditions before it will be possible to understand and evaluate all ramifications of this combustion process.

From the outset of our development work on this process, it has been apparent that, in addition to the use of air as the injection gas, the following schemes of operation might be appropriate under different circumstances:

1. Injection of Fuel Gas — In those cases where the fuel available from the in-place oil is insufficient for supporting combustion, it may be necessary to inject fuel gas. This operation would require careful control of oxygen and fuel gas contents of the injected gas stream so as to avoid mixtures in the explosive range. The injection of an explosive gas could result in an

underground explosion and destruction of the injection well.

2. Use of "Recycle" Produced Gases — Cycling of the produced gases, if discharged from the production wells at elevated pressure, would decrease compression costs but might require pumping larger volumes of gas because of its low oxygen concentration.

3. Oxygen Enrichment of the Injected Gas Stream — Enrichment of the injection gas stream with pure oxygen would offer the advantage of a lower (total gas) injection rate at a lower injection pressure. This type of operation might be important in fields of low effective gas permeability and the economics would depend to a great extent upon the cost of oxygen.

4. Addition of Catalysts to the Injected Gas Stream — The use of catalysts presents many advantages, among which is the selectivity of some catalysts which promote combustion toward carbon monoxide rather than carbon dioxide. This type of catalyst would effectively reduce oxygen requirements and result in lower compression costs.

5. Burning Less than the Full Areal Sweep Possible — As pointed out in our earlier publication, we believe a method of operation involving partial areal burning has considerable merit. This would involve first creating a region of hot sand. Then, combustion would be stopped and the heat contained in the burned region would be transferred to the unburned portions of the reservoir, resulting in an increase in formation temperature in the unburned region. In this method, oil production would be enhanced through a reduction in viscosity and an increase in gas pressure.

Any specific application of the in-situ combustion process would probably involve at least one or more of the above methods of operation, in various possible combinations. More important, such an analysis brings out a point which cannot be over-emphasized in considering the thermal recovery of oil: It will not be possible to stereotype the method of operation. On the other hand, this process will undoubtedly have to be designed and modified to meet the conditions for each and every reservoir. As an example, it may be necessary to prepare or condition a reservoir for gas injection before in-situ combustion can be applied.

Another critical factor which enters into the above five examples of operation involves fuel consumption. Our laboratory investigations have shown that the type of crude oil, the magnitudes of fluid saturations, and the formation characteristics (especially porosity and permeability) have important influences upon the amount of fuel available for combustion from within the formation. In the case of heavy crude oils, the fuel available to the combustion zone is usually plentiful, but in the case of light crude oils, the opposite appears to be true. Light crude oils have such high fluidity that they tend to move away from the combustion front too rapidly to leave adequate amounts of fuel for supporting combustion. Among several remedial steps, an obvious one is to inject a fuel gas with the oxygen-carrying gas in order to supplement the reservoir's low fuel supply. For any specific reservoir, suitable economic analysis will govern the choice of alternative methods of operation.

The Magnolia Petroleum Company's Field Research Laboratories have carried out numerous studies in the laboratory upon the thermal recovery of oil by in-situ combustion. In addition, one field test[1] has been completed and a second field test employing a five-spot well pattern is now in progress. Our work has been directed toward recovery of heavy viscous crude oils that defy economic production by the conventional secondary recovery methods: waterflooding and gas drive. As a result of this work, we do not agree with the authors' implications about the strong dependence of the process economics on restricted ranges of injected gas composition and reservoir oil content. In our opinion, a method of operation involving partial areal burning (method "5" above), with the possible use of oxygen enrichment and catalysts (methods "3" and "4"), will apply to a number of thermal recovery operations, especially for recovery of heavy crude oils.

In conclusion, it is gratifying to know of other investigations in the field of oil recovery by thermal methods. We reiterate that only after a number of actual field experiments on in-situ combustion have been completed can the process be evaluated and the economics of commercial applications be determined.

REFERENCE

1. Kuhn, C. S., and Koch, R. L.: "In-Situ Combustion — Newest Method of Increasing Oil Recovery," *Oil and Gas Jour.*, **52** (Aug. 10, 1953), 92.

AUTHORS' REPLY to H. J. RAMEY, JR.

In answering Ramey's discussion, we would like to point out that our initial approach to the problem of oil recovery has been apparently different from his. Our primary goal, even if it seems set somewhat high, was to recover substantially all of the oil left in the reservoir. Considerations of relative permeability and of mobility ratios seem to indicate that this is not possible by moving the oil in the liquid state; rather, the oil has to be vaporized in order to obtain substantially complete recovery.

As mentioned in our paper, we did not claim to have completely developed our recovery process for all possible reservoir conditions; we stated that more work has to be done before we know all engineering data.

The field test results presented in our paper afford a logical basis for engineering a recovery process which will move oil within the formation as a vapor.

Changing oil from non-mobile status to mobile status is essential. We have outlined one definite method for accomplishing this. It can be done economically by high pressure gas recycling with minimum air usage.

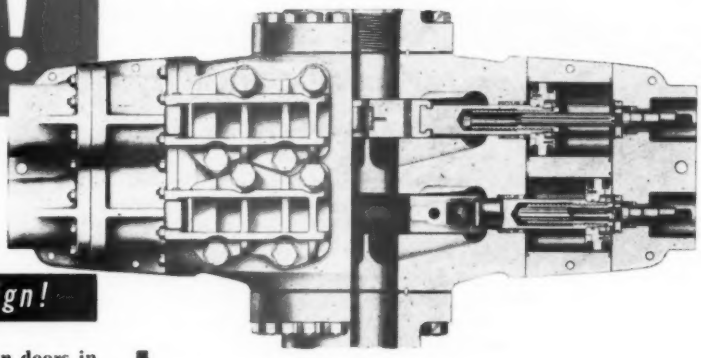
As regards the various alternatives offered by Ramey, they are of course possible, but they do not offer a definite single alternative to the method proposed in this paper. ★★★

To get the industry's

Most Advanced
CELLAR CONTROL GATES

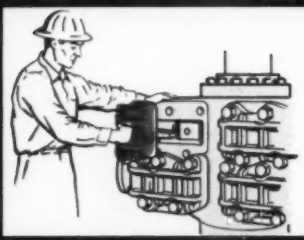
On every point essential to modern control gate protection Shaffer Hydraulic Cellar Control Gates are years ahead in design, in construction, in field-proven dependability.

SPECIFY SHAFFER!



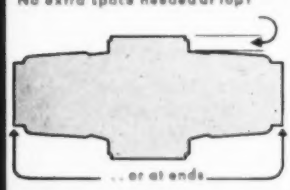
Only Shaffer Gates give you:

1. The Simplicity of Side-Door Design!



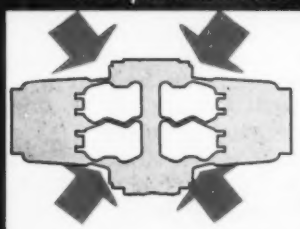
To change rams, simply open doors in the side of the Gate, replace rams, and bolt the doors shut again. It's the quickest, most convenient design available—*and it's exclusively Shaffer!*

2. Compactness that Means Something!



Side door design means that rams are changed where there's plenty of room in the cellar—alongside the Gate. There's no need to expand critical *length* dimensions—or allow extra room *above* the gate—to change rams!

3. Equal Convenience—Top or Bottom!



With Shaffer Hydraulic Double Gates there's no need to disassemble the upper unit to change rams in the lower unit. *Either* compartment can be serviced with equal simplicity—without disturbing the other compartment!

These Shaffer Advancements are important, too...

1. Completely Enclosed Design, with no exposed moving parts to become damaged or jammed.
2. Self-Draining Compartment Bottoms, with rams traveling on guide ribs, high above any detrimental mud or sand that might accumulate.
3. Direct Hydraulic Drive, without secondary connections or complicated arrangements for closing and opening the rams.
4. Choice of Double or Single Gates in all sizes—select the type that best meets your individual requirements.

REMEMBER—in addition to all their other advantages, Shaffer Hydraulic Cellar Control Gates have been field-proven by years of actual field service under widely-varying conditions. Before you invest in any cellar control gates be sure to get complete details on the industry's *most modern* gates from your Shaffer representative. Or write direct.

31 YEARS OF OIL TOOL LEADERSHIP

SHAFFER

HIGH PRESSURE DRILLING AND CONTROL EQUIPMENT • FISHING TOOLS THAT EXCEL

SHAFFER TOOL WORKS, Brea, California • California Service Shops: Santa Fe Springs and Taft
HOUSTON, TEXAS, 6006 Navigation Blvd. • ODESSA, TEXAS, 1925 West Second Street
OKLAHOMA CITY, OKLAHOMA, Acme Oil Tool Company, 1001 S. E. 29th STREET
FARMINGTON, NEW MEXICO, Shaffer Tool Works, Post Office Box 546
CASPER, WYOMING, Shaffer Tool Works, Post Office Box 1788
EXPORT SALES OFFICE: Shaffer Tool Works, 500 Fifth Avenue, New York, N. Y., U.S.A.

Have you a copy of the latest Shaffer Catalog? If not, we'll gladly send you a free copy.

See the Shaffer Section of your Composite Catalog.

A BLOTTER-TYPE ELECTROLYTIC MODEL DETERMINATION of AREAL SWEEPS in OIL RECOVERY by IN-SITU COMBUSTION

H. J. RAMEY, JR.
JUNIOR MEMBER AIME
G. W. NABOR

MAGNOLIA FIELD RESEARCH LABORATORIES
DALLAS, TEXAS

T. P. 3798

ABSTRACT

A blotter-type electrolytic model was utilized to prepare flow diagrams for a field test of the in-situ combustion process. It is pointed out that the areal sweep of a combustion pattern is similar to sweep patterns that would be developed at an infinite mobility ratio, which exists (approximately) across a combustion front because of the complete removal of liquids from the sand behind it.

The precision of the blotter method was tested by comparison with results obtained by other techniques and was found to be satisfactory. The blotter-type model will not furnish as much information as more elaborate and expensive potentiometric models, but its speed of operation and ease of construction make it a highly satisfactory tool to determine areal sweep patterns. A tabulation of sweep efficiency and mobility ratio is furnished for various well geometries.

INTRODUCTION

In connection with the first field experiment with the in-situ combustion method of oil recovery,[5] flow diagrams for the unique well geometry and boundary conditions involved in the subject test were developed. From these diagrams, information concerning the areal sweep and distribution of flow was obtained. A survey of the literature on potentiometric models, utilized to solve two-dimensional flow problems,[1,2,4,6,8,9,10] indicated that the information desired could be obtained by means of a blotter-type model by making certain modifications in the technique. The following discussion describes the application of the modified blotter-type electrolytic model to the solution of the problem of the flow of gases in an oil reservoir for an engineering appraisal of the progress of the combustion front during the first field experiment.

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office Jan. 29, 1954. Paper presented at the AIME Annual Meeting in New York City Feb. 13-17, 1954.

THEORY

Considerable information has been published on the theoretical aspects of electrical model techniques. One author stated that:[6]

> "The models are based on the observation that since the velocity of an ion in an electrolytic system is proportional to the potential gradient, just as the velocity of a fluid particle in a porous medium is proportional to the pressure gradient, the paths of the ions in the electrolytic systems must be similar to those of the fluid particles in a porous medium with the same geometry and equivalent boundary conditions."

This suggestion of a real analogy has been established repeatedly by comparisons of analytic derivations with model results.

The analogy between the movement of a combustion front and the model results is not as apparent, since the combustion process differs from water flooding and gas cycling in that the velocity of the burning front is different from the velocity of the injected fluid at the front in combustion. Analogy between electric current flow and movement of the burning front exists because the local velocity of the burning front is proportional to the air (mass) velocity at this point (assuming frontal temperatures are at least as high as the ignition temperature of the fuel).

Most model studies fall into one of two categories: (1) electron conduction, or (2) ionic conduction models. Examples of these are models which employ as flow media either a thin metal sheet, or a porous blotter saturated with an electrolyte, respectively. Of the two, the porous blotter model, an ionic conduction model, appears to be the most adaptable to the flow problem that results when using in-situ combustion. This problem requires that the mobility of the particles in the model be controlled analogous to the mobility of gas flowing through burned sand of high permeability to gas and then through oil sand of lower permeability to gas. Although the blotter model has heretofore been

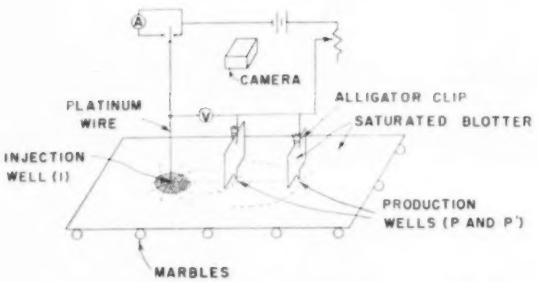


FIG. 1 — SCHEMATIC DIAGRAM OF APPARATUS.

employed solely for study of unit mobility ratio,* it was believed possible to study high mobility ratios by using paints[2] of relatively high conductivity to represent the burned sand. The model has the further advantage that it may be constructed of inexpensive apparatus and operated easily and rapidly. The main disadvantage of this type of model is that it is difficult** or perhaps even impossible to determine the flow streamlines and the potential distribution.

EXPERIMENTAL METHOD

A schematic diagram of the blotter model apparatus is shown in Fig. 1. A plane through a homogeneous oil reservoir is represented by a porous blotter saturated with an aqueous 0.2 N potassium sulfate solution containing about 12 ml of a saturated alcoholic solution of phenolphthalein per liter of salt solution. Direct current enters at the cathode, a 20-gage platinum wire which corresponds to the injection well, flows through the main blotter, and out the smaller blotters. The point of contact between the main and small blotter represents each production well. The voltage drop from the cathode to the point of contact between the main blotter and the nearest production blotter was controlled at 20 v/cm of distance between the contact points of the cathode wire and the anode blotter. Direct current was supplied by a variable output voltage d-c power supply rated at 300 v and 0.1 amps. The blotter was supported by glass marbles to minimize film conduction along the surface of the blotter. A camera, mounted above the plane of the blotter, could be used to record the progress of the ions as indicated by the color change.

The fundamental basis, or chemistry, of the blotter model operation has been well developed by other authors[6,9,10] and will therefore be only briefly reviewed here. In principle, the hydroxyl ions migrate from the injection well (cathode), represented by the platinum wire, through the saturated blotter and toward the production well (anode). These OH^- ions react with the phenolphthalein indicator to form a red color which allows a record of the path of the ions with increasing time. Simultaneously, the hydrogen ions migrate in the opposite direction, and reduce the red color upon contact with the color front. Judicious choice of the size of the small production well blotter allows the OH^- ions to reach the point of contact between the small and large blotters representing the production well, before the H^+ ions move from the alligator clip supporting the small blotter to the contact point with the main blotter. Usually the production well blotters were constructed as a square with sides equal to the well spacing. It would be possible to have any number of producing wells by using additional contacting blotters.

The color front must move at a rate greater than the rate of diffusion of the ions in the saturated blotter to prevent a fuzzy appearance at the front. Generally, less than one hour was required to run a pattern with a 3 to 6 cm well spacing, the time depending upon the voltage gradient employed.

The infinite mobility ratio studies were accomplished by painting succeeding incremental frontal shapes with conductive silver paint,[2] and advancing the front by small increments. This technique was quite convenient inasmuch as the paint could be applied precisely and it dried rapidly. The progress of the fronts in infinite mobility ratio studies were not photographed, because the series of painted blotters furnished a permanent record which could be traced or copied for enlargement. An alternate method of operation was investigated which involved cutting metal templates to the shape of the succeeding fronts; this technique gave results comparable to the conductive paint method, but was far slower.

Model studies were run for an isolated two-spot well pattern for both the unit and infinite mobility ratios, an isolated three-spot well pattern for the infinite mobility ratio, and the combustion field test well pattern for both unit and infinite mobility ratios.

MOBILITY RATIO

Early in the development of the "in-situ" combustion oil recovery method, it appeared that the flow of gas in the combustion process might be somewhat analogous to the flow involved in gas injection and water flooding. However, the combustion process is unique in that the velocity of the burning sweep front is different from the velocity of the injected air at the combustion front. Analogy does exist, since the local

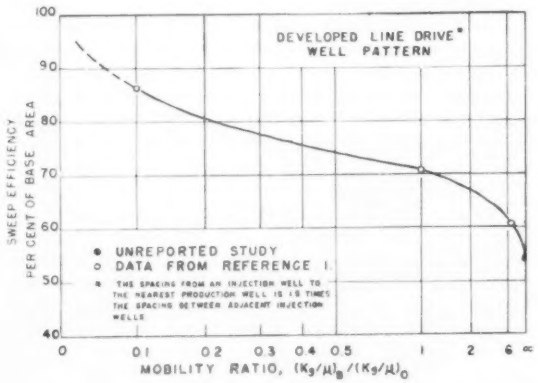


FIG. 2 — CORRELATION OF SWEEP EFFICIENCY AND MOBILITY RATIO FOR A DEVELOPED LINE DRIVE FLOW PATTERN.

*"Mobility ratio" is defined as the ratio of the mobility of the gas in the burned zone to the mobility of the gas in the unburned oil sand. Symbolically speaking, mobility ratio is $(k_g/\mu_g)_B/(k_g/\mu_g)_O$.

**Although flow streamlines are not determined directly from a blotter study, the flux of gas flow along an interface in the case of infinitely high mobility ratio can be calculated since the interfaces are isopotential surfaces. Flow streamlines necessarily are perpendicular to such an isopotential surface.[7]

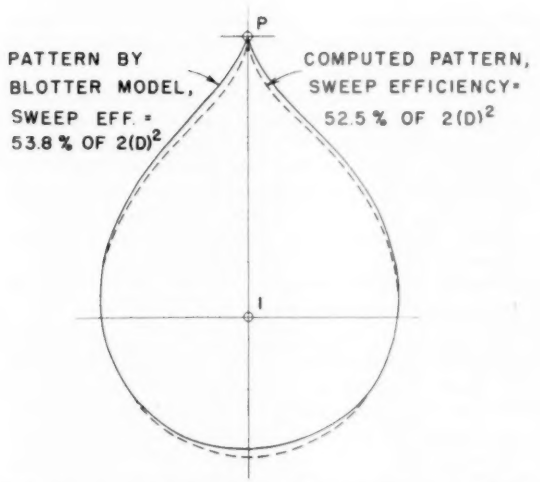


FIG. 3 — COMPARISON OF AREAL SWEEP AT BREAKTHROUGH FOR A COMPUTED AND EXPERIMENTAL ISOLATED TWO-SPOT WELL PATTERN AT UNIT MOBILITY RATIO.

velocity of the burning front is proportional to the air mass velocity at the same point in question.

It was also visualized that the frontal interfaces in the combustion process would be somewhat unique in that the burned region would be at essentially constant pressure and result in an isopotential front. Since it was known that the mobilities in the regions behind and ahead of the front influenced the areal sweep,[1] flow diagrams were developed for the limiting case of the infinite mobility ratio, i.e., wherein the mobility of the gas flowing behind the front was infinitely greater than the mobility of the gas flowing ahead of the front. Results of earlier studies[1] coupled with the results from an unreported study indicate that the mobility ratio can have an extreme effect upon areal sweep efficiency. For example, in a developed line-drive well pattern, sweep efficiency decreases from 87 per cent to 61 per cent for a ratio increase from 0.1 to 10, but decreases only to 55 per cent as mobility ratios go to infinity. This is illustrated in Fig. 2.* If one considers the flow of hot combustion gases from the burned section of the reservoir into relatively cold and unburned oil sand, the mobility ratio during a combustion operation would vary but would normally be expected to be higher than 10. Consequently, in view of the precision possible with an electrolytic blotter model (which will be indicated in the next section), it appears that flow information obtained at an infinite mobility ratio can be applied to in-situ combustion and should give a conservative value for the theoretical sweep efficiency.

*These data were plotted on semi-arctangent coordinates which are very useful for plotting functions that approach a finite limit asymptotically as the variable approaches infiinity. The arctangent scale is based upon the equation:

$$L = \frac{2}{\pi} L_{max} \arctan \frac{M}{0.120_{\pi}}$$

L is the linear distance along the scale measured from the origin; L_{max} is the length of the scale from zero to infinity; M is the value of the variable plotted, the mobility ratio in the present case. The scale modulus, 0.120_{π}, may be changed for best presentation of any particular set of data.

BLOTTER MODEL RESULTS

Initial experimental efforts were concerned with reproducing previously reported results[9,10] in order to establish the precision of the technique. Fig. 3 presents the maximum areal sweep for an isolated two-spot well pattern at unity mobility ratio determined by a blotter study as compared to the computed pattern.[6] The difference between the experimental pattern area sweep efficiency (53.8 per cent) and the computed pattern sweep (52.5 per cent) was 1.3 per cent.

Since no computed patterns were available at infinite mobility ratio, the blotter technique was tested against the results of a model study conducted in a tank-type potentiometric model, wherein succeeding frontal interfaces had been represented by bent strips of a metal conductor. A comparison is made in Fig. 4, which indicates that the difference between the blotter model pattern sweep (66.5 per cent) and the corresponding tank model study sweep (62.0 per cent) is 4.5 per cent. This was considered to be satisfactory agreement.

Fig. 5 presents the areal sweep diagram for the isolated two-spot well pattern at infinite mobility ratio. The sweep efficiency for this pattern was 27.7 per cent of the area represented by 2 (well spacing)², where the well spacing is the distance from the injection to the production well. This sweep efficiency is 24.8 per cent lower than the corresponding unit mobility "breakthrough" sweep of 52.5 per cent.

Fig. 6 presents the areal sweep diagram for a modified two-spot well pattern at unit mobility ratio, wherein the boundary conditions include the addition of a producing well located in-line and one well-spacing further from the first production well. This well pattern is the same as that employed in the field test of the in-situ combustion process reported in reference 5. The areal sweep efficiency was 46.1 per cent, which is 6.4 per cent lower than the isolated two-spot sweep of 52.5 per cent reported in Fig. 3.

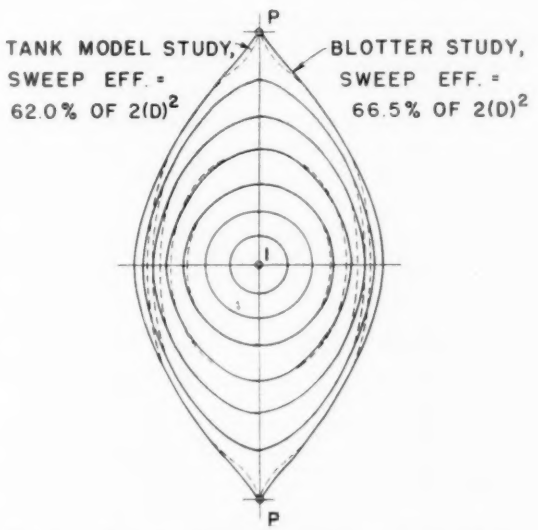


FIG. 4 — COMPARISON OF BLOTTER AND TANK MODEL EXPERIMENTAL AREAL SWEEP DIAGRAMS FOR AN ISOLATED, THREE-SPOT WELL PATTERN AT INFINITE MOBILITY RATIO.

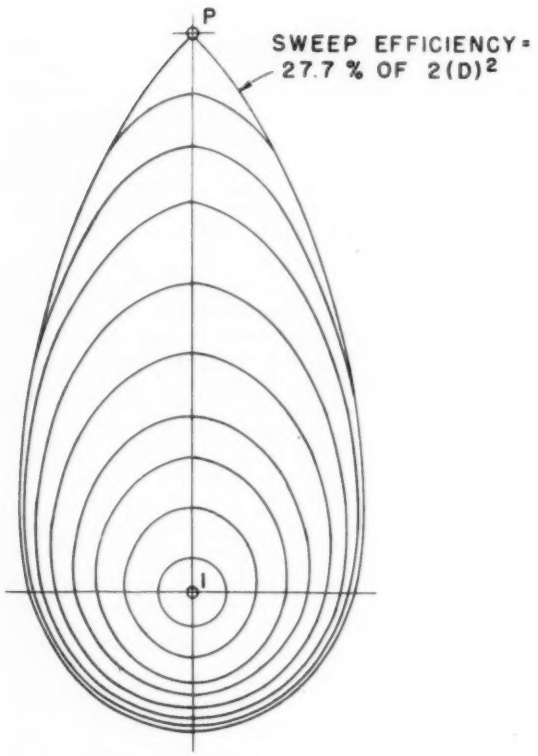


FIG. 5 — AREAL SWEEP DIAGRAM FOR AN ISOLATED, TWO-SPOT WELL PATTERN AT INFINITE MOBILITY RATIO.

Fig. 7 is a flow diagram for the same well pattern as shown in Fig 6, but presents the sweep patterns at infinite mobility ratio. The maximum sweep at breakthrough is 20 per cent, which is 26.1 per cent lower than the corresponding unit mobility ratio sweep of 46.1 per cent reported in Fig. 6, and 7.7 per cent lower than the corresponding sweep of 27.7 per cent for an isolated infinite mobility ratio two-spot pattern.

The foregoing results on areal sweep efficiencies are tabulated below, together with a comparison of the data plotted in Fig. 2 on a developed line drive pattern:

Mobility Ratio	Sweep Efficiencies for Various Well Patterns, Per Cent of Base Area					
	Developed Line-Drive	Isolated Two-Spot		Isolated Three-Spot		Combustion Three-Well Test Pattern
	Pot. Model	Calc	Blotter	Pot. Model	Blotter	Blotter
0.1	86.6					
1	70.8	52.5	53.8	78.5*		46.1
10	61.0					
∞	54.4		27.7	62.0	66.5	20.0

*Calculated value.

CONCLUSIONS

Clearly, the most important conclusion drawn from this study is that the heretofore unreported infinite mobility ratio is approximately a condition one might expect in some in-situ combustion operations. As such, flow diagrams could be quite important and also necessary in the estimation of areal sweeps involved in this type of operation.

Secondly, the blotter-technique may be utilized successfully to obtain high quality areal sweep information for the infinite mobility ratio, rapidly, and with relatively inexpensive apparatus. It is emphasized that other useful information such as flow streamlines and potential distribution may be obtained from more elaborate models. Additional work utilizing tank-type potentiometric models has been undertaken more recently in the study of two-dimensional flow problems as related to in-situ combustion.

In conclusion, it is emphasized that the areal sweep efficiencies reported in this paper in connection with the in-situ combustion oil recovery process cannot be taken in the same sense that areal sweep efficiencies are applied to water flooding to predict ultimate oil recoveries. One main goal of the combustion recovery process is to enhance oil production by means of a reduction in oil viscosity through increased formation temperature. It is conceivable that this beneficial effect could result from burning less than the maximum possible sweep. Further, there is only the result of one actual field test of the new recovery process upon which to base the use of this highly idealized approach to the problem of predicting the effect of burning upon an actual oil reservoir.

ACKNOWLEDGMENT

Acknowledgment is hereby made to the management of the Field Research Laboratories, Magnolia Petroleum Co., for permission to publish this investigation. The writers are further grateful to Rodman Jenkins

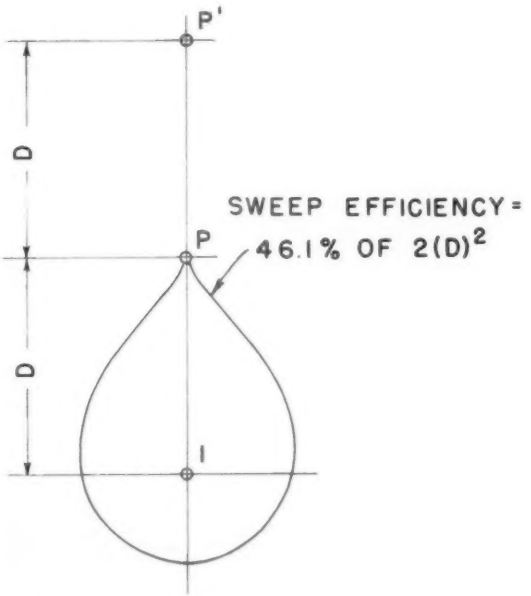


FIG. 6 — AREAL SWEEP AT BREAKTHROUGH FOR A MODIFIED TWO-SPOT PATTERN AT UNIT MOBILITY RATIO ILLUSTRATING EFFECT OF AN ADJACENT PRODUCING WELL.

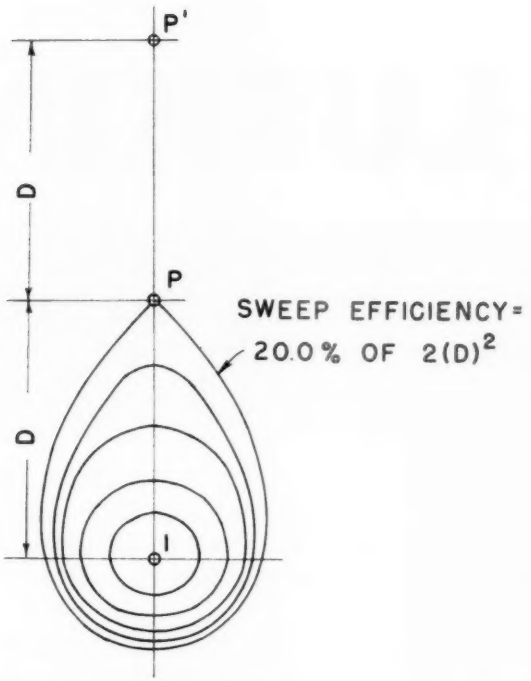


FIG. 7 — AREAL SWEEP DIAGRAM FOR A MODIFIED TWO-SPOT PATTERN AT INFINITE MOBILITY RATIO ILLUSTRATING EFFECT OF ADJACENT PRODUCING WELL.

and William L. Wahl for many helpful suggestions in carrying out the model study and preparation of this manuscript.

REFERENCES

1. Aronofsky, J. S.: "Mobility Ratio — Its Influence on Flood Patterns During Water Encroachment." *Trans.* AIME (1952), **195**, 15.
2. Botset, H. G.: "The Electrolytic Model and Its Application to the Study of Recovery Problems." *Trans.* AIME (1946), **165**, 15.
3. Brunetti, C., and Curtis, R. W.: *Printed Circuit Techniques*, NBS Circ. 468, USDC (Nov. 15, 1947).
4. Horner, W. L., and Bruce, W. A.: *Secondary Recovery of Oil in the U. S.* (1950), 195.
5. Kuhn, C. S., and Koch, R. L.: "In-Situ Combustion — Newest Method of Increasing Oil Recovery," *Oil and Gas Jour.* (Aug., 1953), **204**, 92.
6. Muskat, M.: *The Flow of Homogeneous Fluids Through Porous Media*, (Sec. Pr.), J. W. Edwards, Inc., Ann Arbor (1946).
7. Phillips, H. B.: *Vector Analysis*, John Wiley and Sons, Inc., New York (1944).
8. Swearingen, J. S.: "Predicting Wet-Gas Recovery in Recycling Operations," *Oil Weekly* (1939), **96**, 30.
9. Wyckoff, R. D., Botset, H. G., and Muskat, M.: "The Mechanics of Porous Flow Applied to Water-Flooding Problems," *Trans.* AIME (1933), **103**, 219.
10. Wyckoff, R. D., and Botset, H. G.: "An Experimental Study of the Motion of Particles in Systems of Complex Potential Distribution," *Physics*, (1934), **5**, 265.

NOMENCLATURE

$(k_g)_B$ = effective permeability of burned sand to gas, millidarcys
$(k_g)_O$ = effective permeability of unburned oil sand to gas, millidarcys
$(\mu_g)_B$ = viscosity of gas in burned sand, centipoise
$(\mu_g)_O$ = viscosity of gas in unburned oil sand, centipoise
D = well spacing, feet
I = injection well
M = mobility ratio, $(k_g/\mu_g)_B \div (k_g/\mu_g)_O$
P, P' = production well ★★★

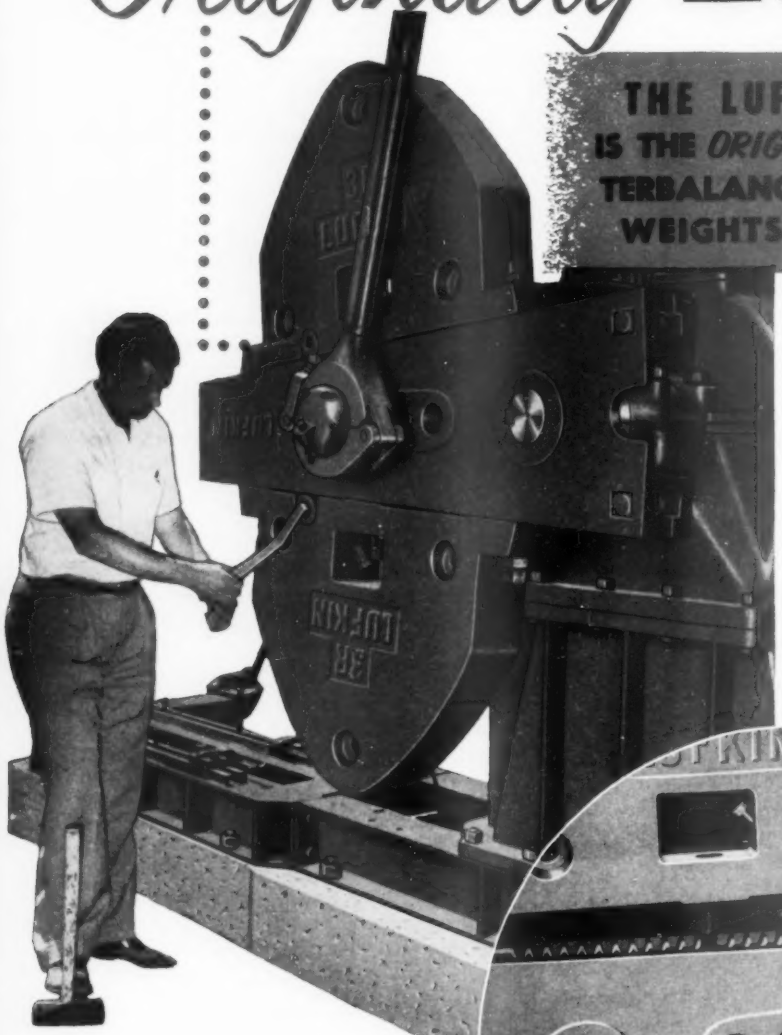
Originally LUFKIN

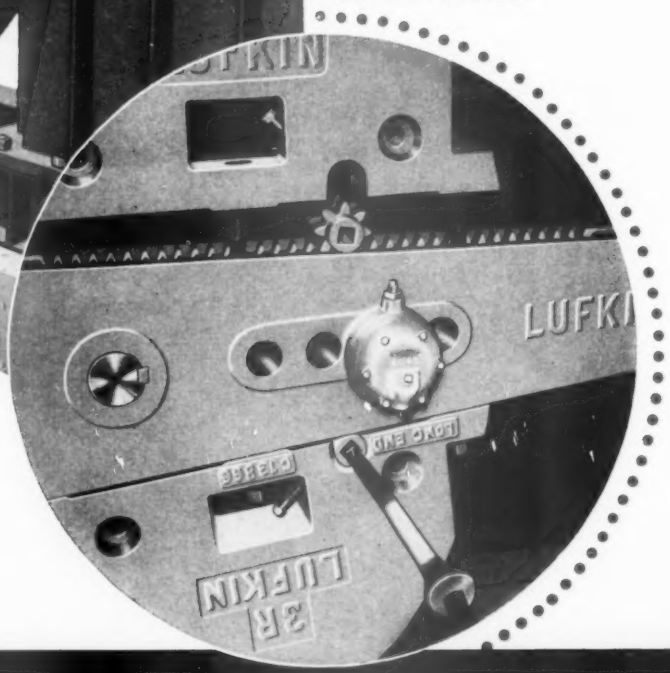
THE LUFKIN TROUT CRANK IS THE *ORIGINAL* ADJUSTABLE COUNTERBALANCED CRANK! NO LOOSE WEIGHTS TO ADD OR REMOVE

NOW BUILT WITH RACK AND PINION FOR GREATER EASE AND CONVENIENCE IN MOVING THE COUNTERWEIGHTS.

ALL FOUR COUNTERWEIGHTS CAN BE ADJUSTED WITHOUT REPOSITIONING CRANKS.

THE SAME RUGGED SIMPLICITY WITH ADDED SAFETY AND CONVENIENCE.





A ONE MAN CREW IS ALL THAT'S NECESSARY

Lufkin **FOUNDRY & MACHINE COMPANY**

LUFKIN, TEXAS

Branch sales and service Houston, Dallas, New York, Tulsa, Los Angeles, Seminole, Oklahoma City, Corpus Christi, Odessa, Kilgore, Wichita Falls, Casper, Wyoming, Great Bend, Kansas, Effingham, Illinois, Duncan, Oklahoma, Brookhaven, Mississippi

Lufkin Equipment in CANADA is handled by

THE LUFKIN MACHINE CO., LTD., 14321 108th Avenue, Edmonton, Alberta, Canada.

THE EFFECT of SURFACE and INTERFACIAL TENSIONS on the RECOVERY of OIL by WATER FLOODING

HARVEY T. KENNEDY
ERASMO T. GUERRERO
MEMBERS AIME

A&M COLLEGE OF TEXAS
COLLEGE STATION, TEX.

T. P. 3796

ABSTRACT

In this investigation, the effects of the surface tension of brine and the interfacial tension between oil and brine on the recovery of oil by water flooding of Woodbine sand were studied. Variation of the surface forces was obtained by the addition of small amounts of commercially available chemicals, which did not appreciably change the surface tension of the oil.

Fourteen surface-active agents, which were found to be effective in lowering the surface and interfacial tensions, were further investigated to determine the extent of their adsorption by the Woodbine Sand cores. It was found that adsorption was sufficient in all cases to prevent any substantial concentration of chemical at the flood front. The flow system was, therefore, brought to equilibrium with definite concentrations in the flood water by circulation before each test. The data thus have no relation to the results obtainable by using the chemicals in full-scale water floods, but should be helpful in predicting the performance of surface-active chemicals which are not lost by adsorption, if such can be found.

Flow tests were made on various concentrations of six chemicals selected from the 14 investigated for surface activity and adsorption, with and without the presence of gas in the core. It was found that lowering the interfacial tension had a tendency toward reducing the recovery of oil and that the reduction of the surface tension of the brine had little or no effect. A substantial beneficial effect, however, resulted from the presence of gas in the cores.

INTRODUCTION

The movement and distribution of crude oil in a porous medium are governed by such factors as surface and interfacial tensions, viscosity of the oil, pore size configuration, and wetting characteristics of the medium. The knowledge of the part played by each of these factors is limited. If the oil is assumed to be distributed in droplets whose movement is restricted only by the pore openings, the following equation may be applied:

$$\triangle P = 2\tau(1/r_1 - 1/r_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In this equation $\triangle P$ is the pressure drop necessary to force an oil droplet through the construction, τ is the oil-brine interfacial tension, r_1 is the radius of curvature at the forward and smaller end of the deformed droplet, and r_2 is the larger radius. This equation neglects the effects of viscosity, as a static or near static condition is assumed. It would apply equally well for a bubble of gas in liquid if τ were taken as the surface tension of the liquid. This relation shows that droplets can be more easily displaced if the interfacial tension is decreased.

The displacement of oil from the surface of a sand particle may also be considered from the basis of selective wetting assuming that the oil droplets are smaller than the pore constructions and that the sand surfaces may be considered as planes. A relation of the forces involved can be derived from Dupre's equation to give:

$$W_{os} = \tau_{ow}(1 + \text{Cos}\,\Theta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where

W_{os} = Work of adhesion between the sand and the oil
τ_{ow} = Oil-water interfacial tension
Θ = Contact angle
τ_{os} = Oil-solid interfacial tension

This equation would indicate that the displacement of oil from a sand surface is more readily obtained when the water-oil interfacial tension is reduced provided the contact angle remains constant. Evidently, however, the values of Cos Θ may vary along with the water-oil interfacial tension due to changes in the other surfaces of the system.

The above theoretical considerations suggest that perhaps even the static behavior of a dispersed oil phase in a porous medium is considerably more complex than may be inferred by the simple systems

[1]References given at end of paper.
Manuscript received in the Petroleum Branch office July 31, 1953. Paper presented at the Petroleum Branch Fall Meeting at Dallas Oct. 19-21, 1953.

presented. In the present investigation, therefore, the effect of brine-gas surface tension and water-oil interfacial tension upon the recovery of oil by water flooding for a system was determined empirically.

Many chemicals which affect the surface forces of the phases present in reservoirs have been added or proposed for addition to flood waters. Nutting[1,2] and Beckstrom and Van Tuyl[3] employed inorganic acids, bases, and salts. Most of these solutions showed no appreciable difference in recovery when compared to a normal water flood except for the dilute solutions of salts formed by the reaction of a strong base and a weak acid. They claimed that this type was effective in increasing the recovery of oil by water flooding.

In the early 1930's work was begun at the Pennsylvania State College on the use of wetting agents to increase oil recovery. In 1934 this[4] laboratory reported increased oil recoveries in waterflooding experiments amounting to as much as 15 per cent by using wetting agents such as sodium sulfo-resinoleate, oleo-glyceryl-sulfates, Gardinol WA, Mapromal Special and Igepon T. In 1936 further tests[4] showed that 4 per cent additional oil could be recovered using Igepon T in the water after normal flooding to the point where no more oil was produced. Further experiments[4] were carried on in 1937, using Ninal No. 555.

In 1947 Terwilliger and Yuster[5] published results that disagreed with the work previously performed. These investigators performed waterflood experiments using both water-soluble and oil-soluble surface-active chemicals. Their results showed that no additional recovery could be obtained by adding these agents to the flood water. Furthermore, their results indicated an excessive amount of adsorption occurring in the case of every chemical tested.

Based on encouraging laboratory tests Breston and Johnson,[6] conducted four field tests with wetting agents and reported favorable results. They claimed increases in production over a limited period of time in excess of 20 per cent.

Laboratory and field tests performed by Morgan, Prusick, and Torrey[7] resulted in their concluding that clear-cut benefits could be obtained by the use of surface-active agents in waterflooding operations.

More recently work has been done on the use of surface-active agents in waterflood operations by Moore and Blum[8] and Caro, Calhoun, and Nielsen.[9] The former did their work with Alundum and Yates sandstone cores and concluded from experimental and theoretical evidence that no increase in oil recovery should be expected from water-wet sands by the use of surface-active agents in the flood water. They did find, however, that some additional recovery could be expected in oil-wet sands.

Caro, Calhoun, and Nielsen[9] did their work on Bradford, Allegheny, and Berea sandstone cores. Their data show additional recoveries due to the wetting agent solutions ranging from a fraction of a per cent up to approximately 7 per cent.

In the present work no agent was found effective in lowering interfacial or surface tensions which was not highly adsorbed on the surface of the sand grains which make up the reservoir rocks. This adsorption has been shown to be a major factor in preventing the movement of chemical at the flood front where it is needed. Although adsorption is mentioned in a few of the investigations cited, it has not been eliminated or corrected for in any of them. Consequently, it appears that in none of the tests reported in the literature cited was there an actual reduction in the surface or interfacial tensions at the flood front. In the present work, this difficulty was overcome by first bringing to equilibrium the fluids and sand surfaces.

DESCRIPTION OF MATERIALS

Cores

In this work two outcrop Woodbine Sand cores, approximately 2-ft long and 2-in. square, were used. Based on microscopic examination the sandstone appeared to be composed chiefly of medium to fine silica grains, iron oxide particles, and clayey materials. The general core data obtained on these cores are shown in Table 1.

Oil, Gas and Brine

The crude oil used for these experiments was obtained from the East Texas oil field and had not been subjected to any type of chemical treatment. As received at the laboratory this oil had a gravity of 39.9° API. For the flow tests this crude oil was saturated with a gas having the composition shown in Table 2.

Synthetic East Texas field brine was used for most of the tests. It was prepared using distilled water and all the components of the East Texas brine except the sodium bicarbonate. This latter component was excluded because in the initial tests it tended to precipitate on the sand grains. The compositions of East Texas field brine and brine used in the tests are shown in Table 3.

Surface-Active Chemicals

Fourteen surface-active chemicals were used in this work. The chemicals by number, trade name, and ionic activity are shown in Table 4. The chemical constitution and properties of these chemicals can be found in the technical literature.

DESCRIPTION OF EQUIPMENT AND PROCEDURE

Density

As part of the supplementary data required in this work, it was necessary to determine the effect of pressure on the densities of saturated and undersaturated East Texas crude oil and synthetic East Texas brine. In the case of oil this was accomplished with the aid of a calibrated metal bomb with a capacity of 262.5 cc.

TABLE 1 – GENERAL CORE DATA

Property	Core A	Core B
Pore volume, cc	517	513
Porosity, percent	38.9	38.4
Air Permeability, md.	3,370	3,700
Brine Permeability, md.	3,021	2,300

TABLE 2 – GAS ANALYSIS

Component	An Analysis of East Texas Gas, mol per cent	Gas Used, mol per cent
Methane	38.05	38.05
Ethane	15.40	15.40
Propane	25.70	46.55
Butane	13.75	
Pentane	7.10	

TABLE 3 – BRINE COMPOSITION

Component	East Texas Brine, PPM	Brine Used, PPM
$NaHCO_3$	756	
NaCl	61,840	61,840
$MgCl_2$	1,095	1,095
$CaSO_4$	407	407
$CaCl_2$	3,552	3,552

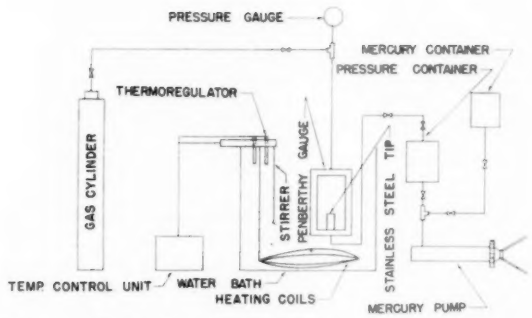


FIG. 1 — FLOW DIAGRAM OF APPARATUS FOR MEASURING SURFACE AND INTERFACIAL TENSIONS.

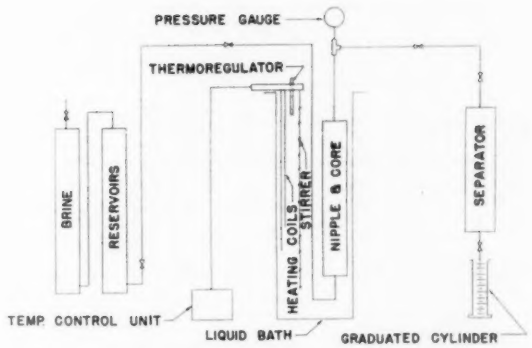


FIG. 2 — FLOW DIAGRAM OF WATER FLOODING APPARATUS.

In determining the effect of pressure on the density of saturated and undersaturated synthetic East Texas brine at 146°F, the only experimental point obtained was that for atmospheric pressure. The remaining data on brine at 146°F, the only experimental point obtained was value and the data of Dodson and Standing[10] which were used to correct the water compressibility constants at different pressures for gas in solution and salinity.

SURFACE AND INTERFACIAL TENSIONS

Surface and interfacial tensions were measured both at atmospheric pressure and 77°F and at higher pressures and 146°F. At atmospheric pressure surface and interfacial tensions were measured with a duNouy interfacial tensiometer. At higher pressures and 146°F the drop weight method was used. The apparatus used is shown diagrammatically in Fig. 1. Both in the measurement of surface and interfacial tensions the recommendations of Hocott[11] in regard to the size of tips were followed.

ADSORPTION

The preliminary adsorption tests on chemicals were performed under atmospheric conditions of temperature and pressure. The equipment used in these tests consisted chiefly of vertical glass tubes 40- to 50-in. long and having an internal diameter of approximately ½ in.

Twenty-five gm samples of unconsolidated Woodbine Sand were placed in each glass column on top of a very small plug of glass wool, used to keep the fine sand from flowing out of the columns. Brine solutions containing a concentration of the chemical to be tested for adsorption were next flowed through this sand. The volume of the effluent was measured and periodically samples of the effluent were taken and checked for chemical content with the duNouy tensiometer. When the effluent gave the same interfacial tension reading against fresh oil as the injected solution, the sand was considered saturated with the chemical at that concentration. The extent of adsorption was calculated from the volume and chemical concentration of the solution passed through the sand.

TABLE 4 — INDEX FOR CHEMICALS

Chemical	Trade Name	Classification as to ionic activity
1	Sterox SE	Non-ionic
2	Span 20	Non-ionic
3	Antarox A-400	Non-ionic
4	Pluronic L-64	Non-ionic
5	Antarox A-200	Non-ionic
6	Ethomid HT/60	Non-ionic
7	Ethomeen S/20	Cationic
8	Ethofat 242/60	Non-ionic
9	Brij 35	Non-ionic
10	Triton X-155	Non-ionic
11	Triton X-100	Non-ionic
12	Ethomid HT/15	Non-ionic
13	Renex	Non-ionic
14	Sterox SK	Non-ionic

FLOW TESTS

In preparation for the flow tests cores were cut to size, coated with Bakelite resin, and set in a section of steel pipe with Wood's metal.

The dead spaces at the ends of the core were measured by determining the weight of the assembly when the spaces were filled with brine and when empty.

Before a flow test was performed, the core was saturated with oil by displacing water with oil in a vertically downward direction. The water displaced from the system was collected in the lower portion of a separator and later measured to determine the amount of oil saturation in the core.

In test runs involving a surface-active agent the chemical was usually placed in the water used to saturate the core. In some of the tests made with oil containing no gas it was dissolved in the oil contained in the system. Circulation of the oil through the initially brine-saturated core for a period of 48 to 72 hours distributed the chemical between the sand, oil, and water. Samples of oil and brine from the system were then obtained and placed against fresh brine and fresh oil respectively. Their interfacial tensions were then measured after a period of 24 hours to determine the equilibrium concentration of chemical in each phase.

Fig. 2 shows the flow diagram of the apparatus used for water flooding. Gas pressure on top of the brine was used to force the flood through the vertical core from bottom to top. The oil flooded out of the core was collected in the upper portion of the separator and later measured with a mercury pump. The rate of flow of the flood was adjusted manually to 600 ± 25 cc/hour with the needle valve on the outlet.

In flow tests where surface-active chemicals were present, their concentration was measured and an amount sufficient to give an equal concentration in the flood water was added. The amount of water used in each flood was 10 pore volumes.

Floods were performed at 1,000, 250, and 125 psig. In the case of the latter two pressures both oil and free gas were present. For these floods production was obtained by pressure depletion from 1,000 to 250 or 125 psig over a period of two hours. A free gas phase

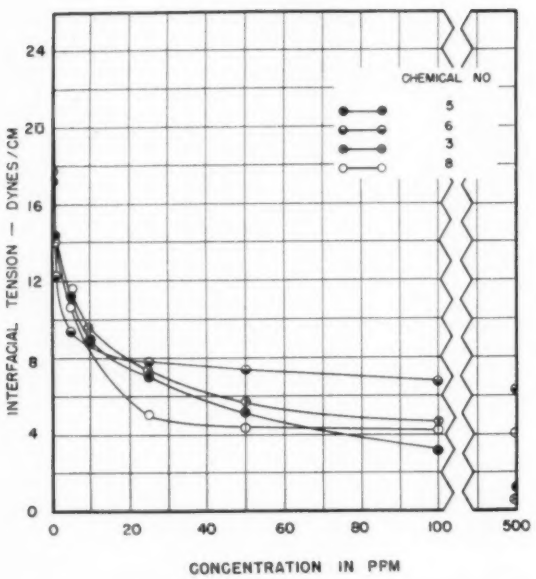


FIG. 3 — THE EFFECT OF VARIOUS CHEMICALS AND THEIR CONCENTRATION ON THE INTERFACIAL TENSION BETWEEN EAST TEXAS CRUDE OIL AND SYNTHETIC EAST TEXAS BRINE AT 77°F AND ATMOSPHERIC PRESSURE.

was formed amounting normally to 25 to 30 per cent of the pore volume.

During these tests six different chemicals were used. To avoid contamination after the use of each chemical, it was necessary to wash the entire system including the core with carbon tetrachloride and water until the washings showed no trace of chemical.

DISCUSSION OF RESULTS

The effect of various chemicals on the interfacial tension between brine and crude oil at atmospheric pressure and 77°F is shown in Fig. 3. These plots show that the chemicals used are very effective in lowering the interfacial tension nearly to a minimum with 10 ppm or less concentration.

ADSORPTION

Fig. 4 shows the adsorption curves for five of the surface-active chemicals tested. In these tests, the sand adsorbed the chemical from solution in the water and in the absence of oil. Later six of the 14 chemicals were selected for use in the flow experiments. It was noticed that some of these chemicals were adsorbed to a lesser degree by the sand grains when the temperature and pressure were increased and an oil phase was present in addition to the water. Table 5 shows the comparison of the adsorption of five surface-active chemicals in the presence and absence of oil and under different conditions of pressure and temperature. It will be noticed that particularly Chemicals 3, 4, and 6 show considerably less adsorption for the sand-brine-oil system at 1,000 psig and 146°F than for the sand-water system at atmospheric pressure and temperature. However, in spite of the much lower adsorption under reservoir conditions and in the presence of oil, it was still prohibitive in magnitude.

TABLE 5 — THE ADSORPTION OF SURFACE-ACTIVE CHEMICALS ON WOODBINE SAND

Chemical	Concentration in Brine, ppm	Adsorption: Sand-Water System at Atm Pres and Temp lb/acre-ft	Adsorption: Sand-Water-Oil System at 1,000 psig and 146°F lb/acre ft
1	100	21,800	15,800
2	10	1,797	1,690
3	250	21,800	2,260
4	75	7,610	1,580
6	25	10,900	1,308

All of the data thus far discussed were supplemental to the waterflooding experiments, which had as their principle objective the determination of the effect of surface and interfacial tensions on the recovery of crude oil by water flooding. It was felt that any other variables affected, such as wettability, would be different for various surface-active chemicals and thus would average out.

Fig. 5 shows the effect of interfacial tension on the recovery of East Texas crude oil by water flooding. As can be noted from the plot, the data for this curve were obtained by using the six chemicals mentioned above. Table 6 in the appendix shows complete data regarding the use of these chemicals in the 17 flow tests plotted in Fig. 5. These tests were not performed in any specific pattern. It can be noted in Table 6 that the two first runs did not involve any chemical. These two were followed by two runs involving high chemical concentrations. This random order should eliminate the effects of any minor changes occurring in the core with time.

Except for the points representing interfacial tensions below 6.5 dynes/cm all of the data for this curve were obtained using undersaturated oil at 1,000 psig having a bubble point of 755 psia. The points for interfacial

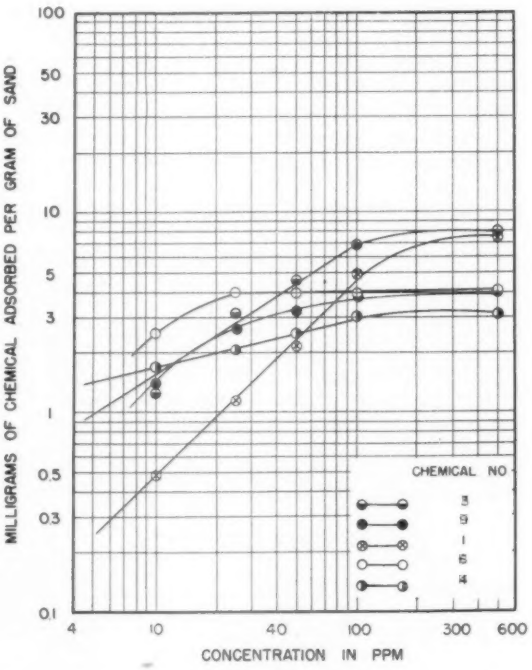


FIG. 4 — THE EFFECT OF CONCENTRATION ON THE ADSORPTION OF SURFACE-ACTIVE CHEMICALS ON UNCONSOLIDATED WOODBINE SAND UNDER ATMOSPHERIC CONDITIONS.

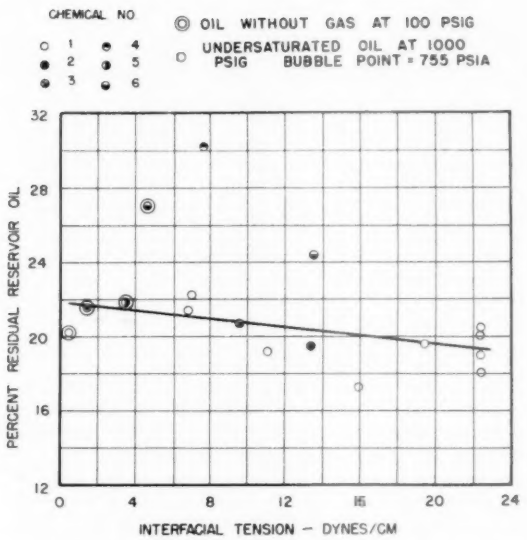


FIG. 5 — THE EFFECT OF INTERFACIAL TENSION ON THE RECOVERY OF EAST TEXAS CRUDE OIL BY WATER FLOODING AT 146°F.

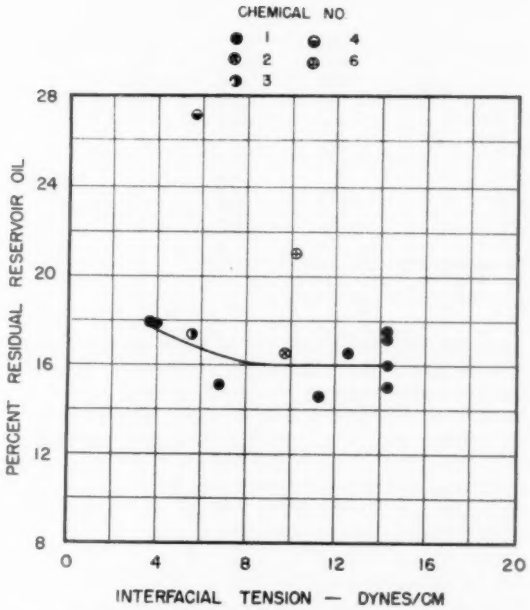


FIG. 6 — THE EFFECT OF INTERFACIAL TENSION UPON THE RECOVERY OF GAS-SATURATED EAST TEXAS CRUDE OIL BY WATER FLOODING FOLLOWING ORIGINAL WATERFLOOD AT 1,000 PSIG AND PRODUCTION BY PRESSURE DEPLETION TO 125 PSIG AT 146°F.

tension values below 6.5 dynes/cm were obtained using oil containing no gas in solution. By using gas-free oil it was possible to lower the oil-brine interfacial tension to 0.4 dynes/cm. The removal of the gas from solution increases the viscosity of the oil from 1 to 5 cp. These values of viscosity were taken from the data of Craze and Buckley[12] and Beal.[13] However, according to the work of Heath[14] the change in viscosity would not affect the recovery as the final water-oil ratios of these tests exceeded 2,000.

It can readily be seen in Fig. 5 that the percentage of residual oil decreases slightly as the interfacial tension is increased. Within the range tested, 0.4 to 22.3 dynes/cm interfacial tension, the difference in percent residual oil is only slightly greater than 2 per cent At 22.3 dynes/cm interfacial tension it can be seen that the reproducibility is about 2.5 per cent to 3.0 per cent. Thus the effect of interfacial tension upon the recovery of crude oil by water flooding was not much greater than the order of magnitude of the error of measurement.

It will be noticed that the curve of Fig. 5 was drawn without considering the data for Chemicals 4 and 6 which show residuals above 24 per cent. These two chemicals had a tendency to change the wettability of the cores. This was supported in two ways. First, 4 to 6 per cent more water was removed in the oil floods involving these chemicals than in the preceding runs. This indicated partial wetting of the sand by the oil and consequently larger initial oil saturations as a result of the greater amount of water removed. When droplets of the oil used in runs involving these chemicals were tested by the sessile drop method using brine from the same run, partial wetting of the silica by the oil was indicated.

After each water flood performed at 1,000 psig, the pressure was dropped to 125 psig and a second water flood was performed at the lower pressure. This was to determine whether or not the presence of a gas-

TABLE 6 — WATER FLOODING TESTS INVOLVING TWO PHASES, SYNTHETIC EAST TEXAS BRINE AND UNDER-SATURATED EAST TEXAS OIL AT 146°F AND 1,000 PSIG BUBBLE POINT — 755 PSIA

Test No.	Core Used	Per Cent Orig. Oil Sat.	Chem. Used	Equilibrium PPM in Brine	Chem. PPM in Oil	Distribution Grams on Core	γ_{o-w}** dynes/cm	Per cent Resid Res Oil	Per cent Resid 60°F and 14.7 psia
1	A	72.5	None	0	0	0	22.3	18.0	14.8
2	A	75.6	None	0	0	0	22.3	20.4	16.7
3	A	71.7	1	100	5,500	14.1	7.0	22.2	18.2
4	A	68.7	1	120	6,500	24.1	6.8	21.4	17.6
5	A	66.4	None*	0	0	0	22.3	18.9	15.5
6	A	67.4	1	.5	20	1.48	15.8	17.2	14.1
7	A	67.0	1	3	150	11.8	11.0	19.1	15.7
8	A	57.1	1	150	8,200	30.5	0.4	20.2	19.5
9	A	68.3	1	.02	1	0.5	19.3	19.6	16.1
10	B	71.8	None	0	0	0	22.3	20.6	16.9
11	B	68.8	2	10	130	1.5	13.3	19.3	15.9
12	B	71.4	3	250	250	2.02	9.5	20.8	17.1
13	B	66.9	3	400	400	13.30	1.4	21.7	20.7
14	B	73.1	4	75	50	1.40	7.8	30.4	24.9
15	A	68.7	5	90	90	4.84	3.4	21.9	20.9
16	A	70.0	6	25	25	1.16	13.6	24.3	19.8
17	A	72.3	6	100	100	383	4.3	27.1	25.9

*Chemical from previous run was removed with CCl_4 and fresh brine.

**Oil-water interfacial tension.

FVF determined from the tests above = 1.22

FVF reported for the East Texas Field oil = 1.23

γ_{o-w} Oil-Water interfacial tension

TABLE 7 — WATER FLOODING TESTS INVOLVING THREE PHASES; EAST TEXAS SYNTHETIC BRINE, EAST TEXAS GAS-SATURATED OIL, AND NATURAL GAS TEMP = 146°F PRESSURE = 125 PSIG

Test No.	Core Used	Per cent Orig Oil Sat.	Per cent Orig. Gas Sat.	Equilibrium		Chem Distribution		γ_{w-o} dynes/cm	γ_{w-g} dynes/cm	Per cent Resid Oil at 125 psig	Per cent Resid Oil at Stnd Cond
				Chem Used	PPM in Brine	PPM in Oil	Grs on Core				
1	A	16.2	28.0	None	0	0	0	14.3	60.6	16.0	14.4
2	A	18.3	28.2	None	0	0	0	14.3	60.6	17.5	15.9
3	A	19.9	25.1	1	100	5,500	14.1	4.0	33.4	17.8	16.0
4	A	19.2	24.0	1	120	6,500	24.1	3.7	31.1	17.9	16.2
5	A	17.0	22.6	1	0	0	0	14.3	60.6	15.0	13.7
6	A	15.4	22.1	1	.5	20	1.48	11.2	51.7	14.6	13.3
7	A	17.1	22.5	1	3	150	11.8	6.8	45.2	15.1	13.8
8	A	17.6	22.8	1	.02	1	0.5	12.3	59.4	16.4	15.0
9	B	18.5	26.5	0	0	0	0	14.3	60.6	17.7	16.1
10	B	17.4	25.8	2	10	150	1.5	9.9	56.5	16.4	15.0
11	B	18.7	25.6	3	250	250	2.02	5.8	47.7	17.4	15.9
12	B	27.7	27.9	4	75	50	1.40	5.5	35.8	26.7	24.4
13	A	21.8	27.0	6	25	25	1.16	10.3	52.4	20.9	19.1

FVF determined from the above tests = 1.095

γ_{w-o} Oil-Water interfacial tension

γ_{w-g} Water-Gas surface tension

liquid interface along with the oil-brine interface would tend to lower the residual oil saturation. Normally the additional recovery amounted to only 1 to 2 per cent. And as Figs. 6 and 7 show a reduction of the surface and/or the interfacial tension resulted in only small effects upon the recovery. In these plots as in Fig. 5, the reproducibility is about 3 per cent. Again the curves were drawn without any consideration to the data of Chemicals 4 and 6.

Figs. 8 and 9 show the effect of surface and interfacial tensions upon the recovery of oil by water flooding following production by pressure depletion from 1,000 to 250 psig at a temperature of 146°F. These curves show that a reduction of the surface and interfacial tensions under these conditions does not affect the production of oil by water flooding within experimental error. Although the residual saturations varied from 8 per cent to 21.8 per cent, this does not represent the errors in the method employed, since considerable variations in the wetting properties of the chemicals and the gas saturations before flooding were involved.

As was seen in connection with Fig. 5, the wetting properties are of primary importance in determining residuals. As will be seen later, the gas saturation before flooding is likewise an important variable. Thus, it will be noticed that two runs are shown for an interfacial tension value of 7.6 dynes/cm and a surface tension value of 47 dynes/cm. Run 6 has a 12.3 per cent residual whereas Run 5 has an 8 per cent residual. The two runs differed in the gas saturation present at the beginning of the water floods due, perhaps, to a slight difference in the rate of pressure depletion. The gas saturation for the 8 per cent residual oil run was 18.9 per cent and for the 12.3 per cent residual oil run 24.4 per cent. In addition to this variation, it will be noticed that here, as well as in the other plots discussed above, the data for Chemical 4 shows much less recovery than that for the other chemicals.

Fig. 10 shows the effect of the gas saturation, before water flooding, just mentioned. The close grouping of points about the curve indicates that the gas satura-

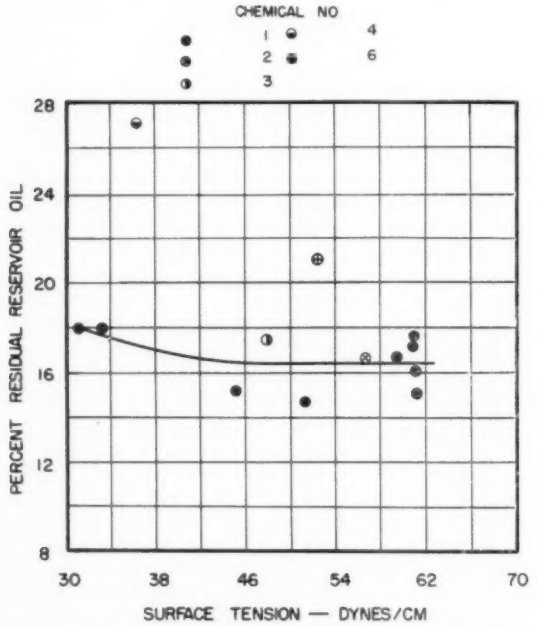


FIG. 7 — THE EFFECT OF BRINE-GAS SURFACE TENSION UPON THE RECOVERY OF GAS-SATURATED EAST TEXAS CRUDE OIL BY WATER FLOODING FOLLOWING ORIGINAL WATER FLOOD AT 1,000 PSIG AND PRODUCTION BY PRESSURE DEPLETION TO 125 PSIG AT 146°F.

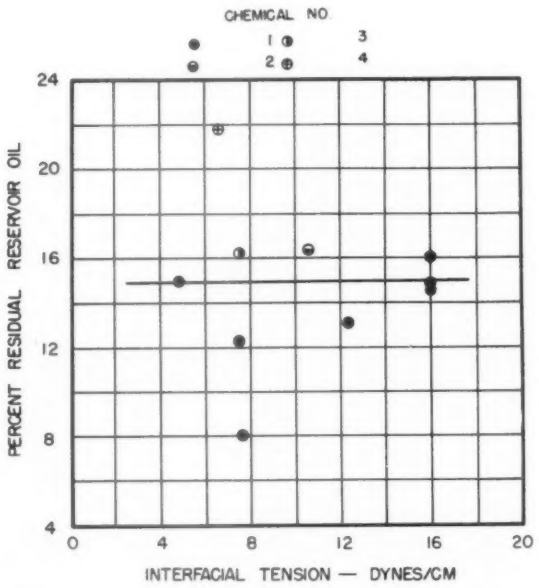


FIG. 8 — THE EFFECT OF INTERFACIAL TENSION UPON THE RECOVERY OF GAS-SATURATED EAST TEXAS CRUDE OIL BY WATERFLOODING FOLLOWING PRODUCTION BY PRESSURE DEPLETION FROM 1,000 PSIG TO 250 PSIG AT 146°F.

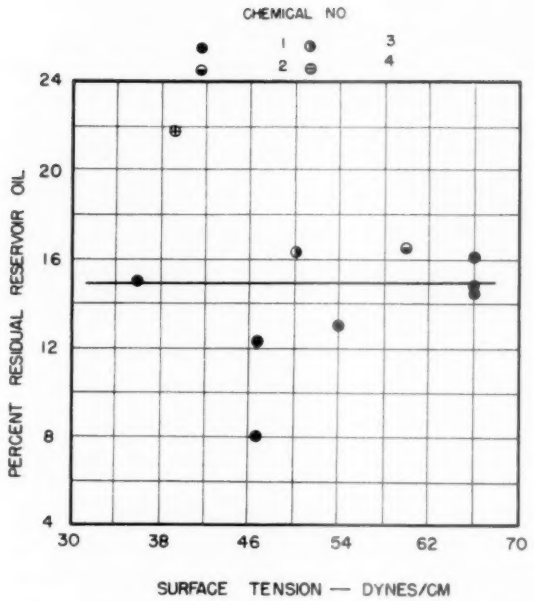


FIG. 9 — THE EFFECT OF BRINE-GAS SURFACE TENSION UPON THE RECOVERY OF GAS-SATURATED EAST TEXAS CRUDE OIL BY WATER FLOODING AT 146°F. SURE DEPLETION FROM 1,000 PSIG TO 250 PSIG AT 146°F.

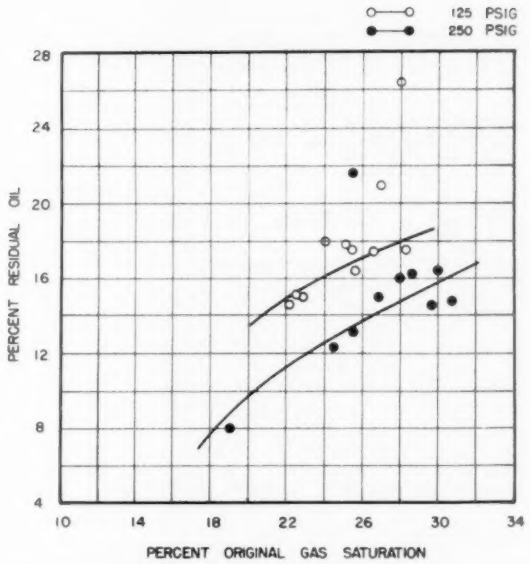


FIG. 10 — THE EFFECT OF ORIGINAL GAS SATURATION ON THE RECOVERY OF GAS-SATURATED EAST TEXAS CRUDE OIL BY WATER FLOODING AT 146°F.

tion is a more important variable than the surface and interfacial tensions of the liquids. It is seen from Fig. 10 that within the range tested the percentage of residual oil decreases as the percentage of initial gas saturation decreases. Here again, the data for those chemicals which tended to make the sand oil-wet were not considered in plotting the curves.

The data from Figs. 5, 6, and 8 are re-plotted in Fig. 11 using as ordinate the stock tank oil equivalent to the reservoir oil residuals previously plotted, by using the formation volume factors given in Tables 6, 7, and 8 of the appendix. These data show that approximately 3 to 4 per cent more recovery can be obtained if gas is present in the porous medium.

Fig. 12 is plotted in a similar manner as Fig. 11 using the data of Figs. 7 and 9. Here it is seen that a greater recovery was obtained by a single water flood following pressure depletion than was obtained for a water flood performed on a core which had been previously waterflooded at a pressure above the bubble point and pressure depleted.

No agreement can be seen between the results of this investigation and the theoretical predictions made by water flooding a core which has been previously that if the oil phase is distributed as droplets in the porous medium, the recovery of the oil should be increased by decreasing the interfacial tensions between the liquids. In the tests described a slight contrary effect of less production, or no effect at all, is observed. This may signify that the oil does not occur as segregated droplets, as commonly assumed.

CONCLUSIONS

The data obtained from this study support the following conclusions as applied to the conditions under which the investigation was made.

1. Reduction of the interfacial tension between oil and brine reduces slightly the recovery of oil by water flooding above the bubble point.

2. At pressures below the bubble point, in the presence of gas, reduction of interfacial and surface tensions of the liquids has a small or negligible effect on recovery. However, the presence of gas, regardless of the surface and interfacial tensions, exerts a substantial beneficial effect on the recovery.

3. No appreciable additional oil can be obtained by water flooding a core which has been previously

TABLE 8 — WATER FLOODING TESTS INVOLVING THREE PHASES; EAST TEXAS SYNTHETIC BRINE, EAST TEXAS GAS-SATURATED OIL, AND NATURAL GAS TEMP = 146°F PRESSURE = 250 PSIG

Test No.	Core Used	Per cent Orig. Oil Sat.	Per cent Orig. Gas Sat.	Equilibrium Chem Used	Equilibrium PPM in Brine	Chem Distribution PPM in Oil	Chem Distribution Grs on Core	$\gamma_{o,w}$ dynes/cm	$\gamma_{w,g}$ dynes/cm	Per cent Resid Oil at 250 psig	Per cent Resid Oil at Stnd Cond
1	A	42.2	29.6	None	0	0	0	16.0	63.8	14.5	13.1
2	A	43.1	30.6	None	0	0	0	16.0	63.8	14.7	13.2
3	A	38.7	26.8	1	100	5,500	14.1	4.8	35.7	15.0	13.5
4	A	39.8	25.4	1	0.5	20	1.48	12.3	54.0	13.1	11.8
5	A	39.4	18.9	1	3	150	11.8	7.7	46.4	8.0	7.2
6	A	38.0	24.4	1	3	150	11.8	7.7	46.4	12.3	11.1
7	B	38.2	27.9	None	0	0	0	16.0	63.8	16.1	14.5
8	B	38.3	30.0	2	10	150	1.5	10.5	59.1	16.6	14.9
9	B	38.7	28.3	3	250	250	2.02	7.6	49.9	16.3	14.7
10	B	37.2	25.5	4	75	50	1.40	6.4	38.9	21.6	19.5

FVF determined from the above tests = 1.11
$\gamma_{o,w}$ Oil-Water interfacial tension
$\gamma_{w,g}$ Water-Gas surface tension

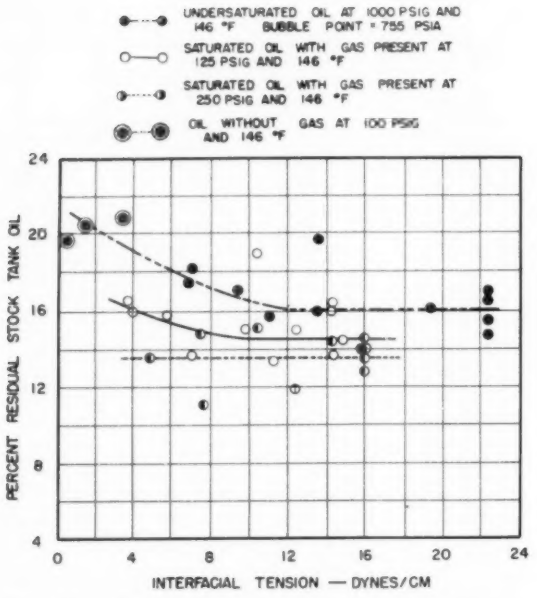

UNDERSATURATED OIL AT 1000 PSIG AND 146 °F BUBBLE POINT = 755 PSIA
SATURATED OIL WITH GAS PRESENT AT 125 PSIG AND 146 °F
SATURATED OIL WITH GAS PRESENT AT 250 PSIG AND 146 °F
OIL WITHOUT GAS AT 100 PSIG AND 146 °F
PERCENT RESIDUAL STOCK TANK OIL
INTERFACIAL TENSION — DYNES/CM

FIG. 11 — A COMPARISON OF RECOVERIES OBTAINED FROM WATERFLOODING EXPERIMENTS WITH VARYING INTERFACIAL TENSIONS

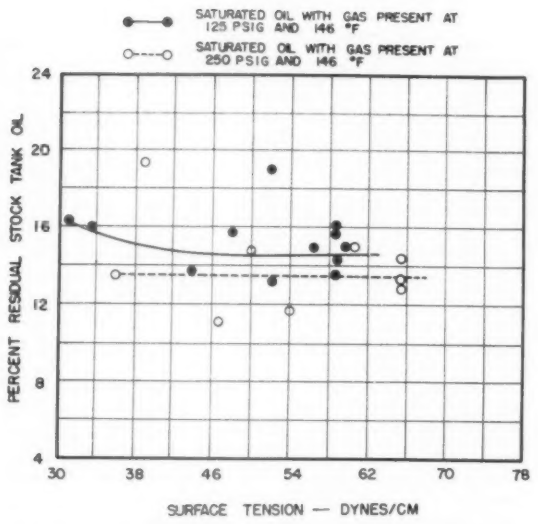

SATURATED OIL WITH GAS PRESENT AT 125 PSIG AND 146 °F
SATURATED OIL WITH GAS PRESENT AT 250 PSIG AND 146 °F
PERCENT RESIDUAL STOCK TANK OIL
SURFACE TENSION — DYNES/CM

FIG. 12 — A COMPARISON OF THE RECOVERIES OBTAINED FROM WATERFLOODING EXPERIMENTS WITH VARYING BRINE-GAS SURFACE TENSION.

waterflooded above the bubble point and pressure depleted.

4. The adsorption of some surface-active chemicals on Woodbine sand is considerably less in a sand-brine-oil system under reservoir conditions than in a sand-brine system under atmospheric conditions. However, all of the chemicals tested are adsorbed in prohibitive quantities.

5. Surface-active agents that change the wettability of a sand from water-wet to oil-wet may reduce the recovery of oil by water flooding as much as 8 per cent.

ACKNOWLEDGMENT

The work performed in this investigation was sponsored by the Magnolia Petroleum Co. through its fellowship funds and by the Texas Engineering Experiment Station through its Project 203. The writers are grateful to these sponsors for their financial contributions without which this work would not have been possible. Thanks are due to the Magnolia Petroleum Co. Field Research Laboratories in suggesting some of the chemicals investigated.

REFERENCES

1. Nutting, P. G.: "Chemical Problems in the Water Driving of Petroleum from Oil Sands," *Ind. Eng. Chem.* (1952), **17**, 1035-36.

2. Nutting, P. G.: "Soda Ash Process for Petroleum Recovery," *Oil and Gas Jour.* (1927), **25** (45), 76, 150.

3. Beckstrom, B. C., and Van Tuyl, F. M.: "Flooding Oil Sands with Alkaline Solutions," *Bull.* AAPG, (1927) **11**, 223-237.

4. Calhoun, J. C., Stahl, C. D., Preston, F. W., and Nielsen, R. F.: "A Review of Laboratory Experiments on Wetting Agents for Water Flooding," *Producers Monthly* (Nov., 1951), **16** (1), 15-23.

5. Terwilliger, P. L., and Yuster, S. T.: "Chemical Agents in Water Flooding," *Oil Weekly* (1947), **126** (1), 54-6.

6. Breston, J. N., and Johnson, W. E.: "Experiments with Wetting Agents in the Bradford Field," *Producers Monthly* (1951), **16** (1), 24.

7. Morgan, L. O., Prusick, J. H., and Torrey, P. D.: "Application of Surface Chemistry to Oil Recovery, Proceedings Fourth Oil Recovery Conference, TPRC (May 8-9, 1952), *Bulletin No. 17, 78.*

8. Moore, T. F., and Blum, H. A.: "Importance of Wettability in Surface-Active Agent Waterflooding," *Oil and Gas Jour.* (1952), **51** (31), 108-111.

9. Caro, R. A., Calhoun, J. C., Jr., and Nielsen, R. F.: "Experiments Show Under What Conditions Surface-Active Agents Increase Oil Recovery," *Oil and Gas Journ.* (1952), **51** (34) 62-3 (86-7).

10. Dodson, C. R., and Standing, M. B.: "Pressure-Volume-Temperature and Solubility Relations for Natural Gas-Water Mixtures," *Drilling and Production Practice*, API (1944), 173-9.

11. Hocott, C. R.: "Interfacial Tension Between Water and Oil Under Reservoir Conditions," *Trans.* AIME (1938-1939), **127** and **132**, 184.

12. Craze, R. C., and Buckley, S. E.: *Drilling and Production Practice*, API (1945), 144.

13. Beal, C.: "The Viscosity of Air, Water, Natural Gas, Crude Oil, and its Associated Gasses at Oil Field Temperatures and Pressures," *Trans.* AIME (1946), **165**, 94.

14. Heath, W. A.: "Influence of Viscosity of Crude Oil on Secondary Recovery," *Secondary Recovery of Oil in the United States*, Second Edition, API (1950), 228-32.

MEET the AUTHORS

BRUCE F. GRANT

Now division director of secondary recovery for Sinclair Research Laboratories, Inc., BRUCE F. GRANT formerly worked for 10 years with the U. S. Bureau of Mines at Franklin, Pa. Before that, he was employed for one year by Shasta Oil Co. He is a 1939 graduate of the University of Texas.

STEFAN E. SZASZ

Born and educated in Bucharest, Romania, STEFAN E. SZASZ came to the U. S. in 1952 and has worked with Sinclair Research Laboratories since that time. He is now assistant project chemist. After receiving his PhD degree in 1939 in physical chemistry from the University of Bucharest, he was employed by Astra Romana, S. A. and by the Petroleum Research Institute of Berlin.

HENRY J. RAMEY, JR.

A senior research engineer at Field Research Laboratories, Magnolia Petroleum Co., HENRY J. RAMEY, JR., joined Magnolia after graduation from Purdue University. He holds BS and PhD degrees (1952) in chemical engineering, his research study having concerned radiant heat transfer from superheated gases.

GEORGE W. NABOR

A chemical engineer, GEORGE W. NABOR holds a BS degree from the University of Wisconsin, and a PhD degree from Purdue University (1953). He is a senior research engineer at the Magnolia Field Research Laboratories. His graduate work was conducted on the reaction kinetics of the sulfur-methane system.

HARVEY T. KENNEDY

Now Distinguished Professor of petroleum engineering at Texas A&M, HARVEY T. KENNEDY received his BS degree from Cornell University and PhD degree from John Hopkins. After six years with the Bureau of Standards and 20 years engaged in the study of problems of the petroleum producing industry, he joined the faculty of Texas A&M.

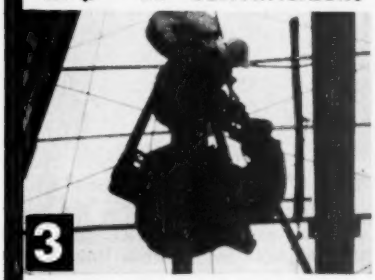
E. T. GUERRERO

Before accepting in 1953 his present position as reservoir engineer with the Seeligson Engineering Committee of San Antonio, E. T. GUERRERO served for a year as an instructor of petroleum engineering at Texas A&M. He holds BS, MS, and PhD degrees from Texas A&M.

3 REQUIREMENTS For a GOOD Cement Job

1 B and W Scratchers

2 B and W LATCH-ON CENTRALIZERS



3 MOVEMENT OF CASING *

*The highest percentage of successful cement jobs result from . . . mud removal and prevention of channelling by . . . movement of the casing, from the time casing reaches bottom until the plug "bumps."

B and W Inc.
Well Completion Specialists

GULF COAST
P. O. Box 5266
Houston 12, Texas
Phone WE 6603

WEST COAST
3545 Cedar Avenue
Long Beach 7, Calif.
Long Beach 4-8366

NOMINEES for PETROLEUM BRANCH OFFICERS for 1955

Officers for the Petroleum Branch for 1955 have been nominated by the Branch Nominating Committee, under the chairmanship of Paul R. Turnbull. Other members of the Committee were: L. E. Elkins, John S. Bell, A. S. Rhea, and A. L. Vitter. Any group of 10 members may submit additional nominations before the closing date of August 15. If no other nominations are received by this date, these nominees will be declared elected. A letter ballot covering all positions for which nominations have been received will be mailed in September, if additional nominations are made. New officers for 1955 will be installed at the Annual AIME Meeting in February, 1955.

FOR CHAIRMAN

ROBERT B. GILMORE is the senior vice-president and a director of DeGolyer and MacNaughton of Dallas, where he has been employed since 1941. Prior to his association with D&M, he worked with the Shell Oil Co. from 1934, in the Mid-Continent areas of Oklahoma, Kansas, and North Texas. He was born and educated in Tulsa, having been graduated from the Universtiy of Tulsa in 1939 with a BS in petroleum production engineering and courses in geology, petroleum refining, and chemical engineering. He has held the position of Petroleum Branch treasurer and is now chairman of the Production Review Committee. He became a Student Associate of the AIME in 1931, and a Member in 1943.

FOR VICE-CHAIRMAN

PHIL J. LEHNHARD is field chairman of the East Texas Engineering Association, Kilgore, having served in that capacity since 1946. He started his work as a petroleum engineer in 1932 with the Humble Oil and Refining Co. in Houston; then, worked with Dowell, Inc., in Tulsa from 1935 until 1944. With the United Oil Well Service, S.A., he went to Caracas, Venezuela, to serve as research and development engineer and later as chief engineer. He returned in 1946 to accept his present position. He is a past chairman and program chairman of the East Texas Local Section and has served for several years on the Board of Directors of that Section. He was graduated from the University of Oklahoma in 1931 with a BS degree in petroleum engineering.

FOR VICE-CHAIRMAN

GEORGE LATHAM YATES is a consulting petroleum engineer and a senior member of the firm of Amstutz and Yates, Inc., Wichita, Kan., having served in that capacity since 1947. He holds a BS degree in petroleum engineering and an MS degree in mechanical engineering from the University of Oklahoma. From 1935 until 1943 he was an instructor and assistant professor in the Department of Oil and Gas at the University of Pittsburgh. In 1944 he joined Standard Oil Co. (Ohio), later to become head of the Valuation Engineering Section of their Production Engineering Department. He is a past chairman of the Kansas Local Section and a member of the Petroleum Branch Executive Committee.

FOR EXECUTIVE COMMITTEE

GEORGE R. GRAY is manager of the Gulf Coast Sales and Service Laboratory of the Baroid Sales Division, National Lead Co. He has served in this Houston position since 1943. A chemist, he holds a BS degree from Texas Christian University and MS and PhD degrees from Rice Institute. Prior to accepting his present position, he worked for eight and one-half years with the Production Research Department of the Humble Oil and Refining Co. He has served as chairman, vice-chairman, and on the Board of Directors of the Gulf Coast Local Section, and was for two years the representative of that Local Section to the Engineering Council of Houston.

FOR EXECUTIVE COMMITTEE

EARL M. KIPP, JR., is the chief engineer for The California Co., having since 1936 worked for Calco and its affiliates. A native Californian, he joined an affiliate company of The California Co. shortly after his graduation from Stanford University. His work carried him to California, Texas, New Mexico, and the Gulf Coast. In 1940 he joined the parent company as a petroleum engineer, and was appointed to his present position in 1946. He has been very active in the Delta Local Section since locating in his New Orleans office. ★★★

Robert B. Gilmore

Phil J. Lehnhard

G. Latham Yates

George R. Gray

Earl M. Kipp, Jr.

Universities Announce Short Courses for Summer Sessions

Short courses are planned during the summer by many universities throughout the nation. Universities in Michigan, Texas, New Mexico, and West Virginia are among those planning such activities.

A course in "Design of Distillation and Absorption Equipment" for engineers in industry will be offered at the University of Michigan July 12 through July 23. R. H. Newton of Badger Manufacturing Co. will be the instructor. The course is designed for engineers with some experience who wish to acquire a working knowledge of design procedures.

An Institute of Advanced Engineering is scheduled for the University of Texas, with three short courses to be offered. The purpose of the courses will be to offer "briefings" to engineers on professional advances which have taken place since their graduation.

Each of the University of Texas courses will last three weeks. "Advanced Experimental Stress Analysis" (June 14 to July 2), "New Developments in Communication Theory" (August 16 to September 3), and "Composition and Properties of Oil Well Drilling Fluids" (August 26 to September 15) are the courses which will be given.

The 14th annual Appalachian Gas Measurement Short Course will be held at West Virginia University, Morgantown, W. Va., August 23-25. The session is attended annually by measurement and control engineers and other technical personnel representing petroleum, gas, and chemical industries. Subjects to be covered will include fundamentals of gas measurement and special sessions on domestic meters, large capacity meters, orifice meters, auxiliary measurement instruments, automatic control instruments, planning and design of installations, and pressure regulators, motor valves and related equipment.

At New Mexico Institute of Mining and Technology a short course in reservoir engineering will be held June 14 to 19. The school is planned primarily for men with professional experience in oil production who are interested in a review of reservoir theory.

John McMillan Named President

John R. McMillan, chairman of the Petroleum Branch, has been elected president of Fullerton Oil Co. He succeeds W. W. Valentine, who resigned following the sale of the Valentine group's interest in the company.

McMillan joined the staff of Fullerton Oil Co. in 1943 as petroleum engineer and assistant manager of field operations. Four years later he was named vice-president and director in charge of production and exploration, the position he has held until his appointment as president.

Geologists Speak to Kansas Local Sections

The Kansas Local Sections held a joint April meeting at the University of Kansas at Lawrence. Two talks were featured at the meeting and a tour of the Petroleum Engineering Department was given.

"The Ocean Is Under Us" was the topic of a paper presented by Willard Hilton, chief geologist of the Oil Field Section, State Geological Survey. "The Geological Survey as a Service Organization" was presented by Ed Goebel of the Oil & Gas Division, State Geological Survey.

Murrell Speaks on Reserves as Collateral For Loans at Permian Basin Meeting; Decker Talks on Value of Membership

More than 170 persons heard John H. Murrell of DeGolyer and MacNaughton, Dallas, speak on "Petroleum Reserves as Collateral for Loans" at the April meeting of the Permian Basin Local Section.

Murrell explained the information which moneylenders desire before making an oil loan and told of the ease of obtaining loans at this time. Then he explained the work of the consultant in estimating reserves as well as in other fields.

Harold Decker, president of Houston Oil Co. and a vice-president of the AIME, was another visiting speaker. He talked on the value of AIME membership.

Petroleum Branch Membership Directory Being Set in Type for June Publication

Printers are now setting type for the 1954 Membership Directory of the Petroleum Branch which will be published in the June issue of the JOURNAL OF PETROLEUM TECHNOLOGY. The Directory will be a removable supplement bound within the outside cover of the issue.

The names and addresses of approximately 6,000 members will be given, listed both alphabetically and cities and states. Included in the listings will be the company affiliations, titles, and mailing addresses of the members.

Advertising will be placed throughout the Directory facing the member listings. Revenue from advertising space has made it possible for the Petroleum Branch to publish its own Directory.

Mississippi Section Officers for 1954 are, left to right: W. I. Sanderson, chairman, Halliburton; E. J. Gray, first vice-chairman, Gulf Refining Co.; Will J. McEver, secretary-treasurer, Lane-Wells; and J. R. Meason, second vice-chairman, State Oil and Gas Board.

Mid-Continent Local Section Officers for 1954 who took office May 1 are, left to right: D. R. Johnson, secretary-treasurer, Gulf Oil Corp.; M. B. Penn, chairman, Mid-Continent Petroleum Corp.; S. F. Bird, first vice-chairman, Amerada Petroleum Corp.; and F. H. Callaway, second vice-chairman, Stanolind Oil and Gas Co.

AVAILABLE JOHNSTON by AL CAPP

YO' JOHNSTONS WINS TH' SAFETY AWARD, AGIN!!-YO' TESTED MORE WELLS THAN ANYBODY!!
NATCHERLY!!-US JOHNSTONS SPESHULIZES IN DRILL-STEM TESTIN', WIF OUR SPESHUL EE-KWIP-MUNT!!
HE IS AVAILABLE, AN'AH IS ACCURATE!

C-542

Copr. Capp Enterprises 1954

JOHNSTON TESTERS

first in drill stem testing

HOUSTON, TEXAS

LOS ANGELES, CALIF. • CALGARY, CAN.

FORMATION AND CASING TESTING — JOHNSTON

AIME-Socony Vacuum Announce Rules For 1954-55 Scholarship

Applications are now being received for the AIME-Socony-Vacuum undergraduate scholarship in petroleum engineering. All applications must be in the hands of the secretary of the AIME Student Relations Committee by June 30, 1954.

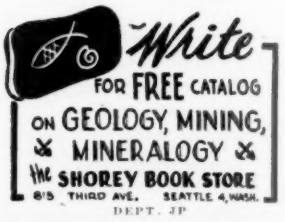
The scholar selected to receive this award must be exclusively an undergraduat who is expected to complete academic work during the academic year 1954-55; that is, upon completion of the award period the recipient is expected to be ready to enter industry. Enrollment in a graduate school eliminates consideration of a candidate.

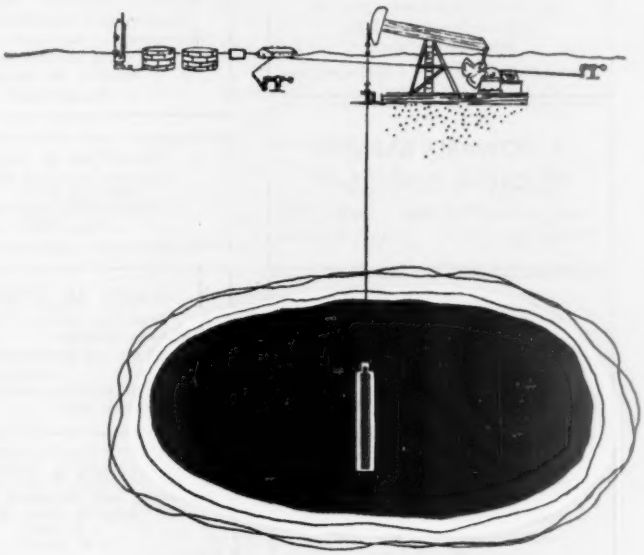
The total grant of the scholarship is $750. Selection of the scholar will impose no obligation in respect to employment upon the recipient or Socony-Vacuum.

Selection of the recipient will be based primarily upon scholastic achievements and certain personal characteristics, such as social consciousness and general employability. Any college in the United States granting a degree in petroleum engineering or giving petroleum engineering as an option is privileged to submit an application.

All applications should be supported by the scholastic record of the candidate and such data and information as will permit the Scholarship Committee to make a suitable selection. Applications should be mailed to: H. Newell Appleton, Secretary Student Relations Committee, AIME, 29 West 39th Street, New York 18, N. Y.

The objectives of this scholarship are to promote the progress of the petroleum engineering profession by recognition of merit and to promote closer relations between the industry and educational institutions. Socony-Vacuum states as its intention the encouragement of scientifically trained people rather than scientific ideas and research.





One good reason for the widespread use of a Harbison-Fischer Double-Displacement Rod Pump in water flood production wells is the operating flexibility of a sucker rod actuated insert pump as compared to centrifugal or reciprocating pumps. Double-Displacement rod pumps also will handle more volume than a tubing pump.

The Double-Displacement Pump is a full insert type assembly with two plungers and barrel tubes in tandem operating with a single set of valves. It seats in a standard cup type seating nipple or the old working barrel in the tubing, and operates like any other conventional insert pump. Double-Displacement Pumps are available in bottom hold-down types in 2" x 1½", 2½" x 2", 3" x 2½" and 4" x 3¼" sizes with these bore constants: 1½"=.408; 2"=.762; 2½"=1.194; 3¼"=1.892. (To calculate production for 24 hrs., multiply S/Min. x length of stroke x constant.)

Double-Displacement Pumps with H-F Flexite Ring Plungers are recommended for wells making water, but Tuff-Temper, Precision, and H-F Composition Ring Plunger assemblies are also available for various well conditions.

Double-Displacement Pumps are in successful operation in various fields throughout the mid-continent area, including many water flood projects. Leading stores will be glad to give you additional information, or write to us for an illustrated bulletin and comparative field test data. Harbison-Fischer Mfg. Co., P. O. Box 127, Fort Worth, Texas. Factory representatives throughout the oil country.

HARBISON-FISCHER

WILSON Double-Displacement PAT. PEND

ROD PUMP

PROFESSIONAL SERVICES

This space available only to AIME members.

AMSTUTZ AND YATES, INC.
Petroleum Engineers and Geologists
Estimates of Oil and Gas Reserves
Property Valuations, Reservoir Analyses
Geologic Investigations
406 KFH BLDG., WICHITA 2, KANS.

PISHNY AND ATKINSON
Engineers and Geologists
Valuation of Oil and Gas Properties
2412 Continental Life Bldg.
FORT WORTH, TEXAS
Chas. H. Pishny — Burton Atkinson

J. HOWARD BARNETT
PETROLEUM CONSULTANT
Casper National Bank Bldg. — Phone 2-1758
113 East Second St. — Casper, Wyoming

ROBERT M. BEATTY
Consulting Geologist
Esperson Building — Houston 2, Texas

W. RUSSELL BIRDWELL
Consulting Petroleum Engineer
PHONE 6-6601 — BOX 1348
Frontier Oil & Gas Bldg.
McALLEN, TEXAS

BRADLEY, OLIVER AND ASSOCIATES
PETROLEUM CONSULTANTS
Geology, Engineering and Management
903 Employers Insurance Building
Dallas, Texas — ST-5331

JOHN G. CAMPBELL
Analytical and Petroleum Chemists
Podbielniak and Charcoal Analyses
Waters - Oil Field Brines
Field Sampling
PHONE: 4-3071 — CORPUS CHRISTI, TEXAS

CHEMICAL & GEOLOGICAL LABORATORIES
Consultants - Investigations - Evaluations
James G. Crawford ..... Chemical Engineer
H. F. Summerford ..... Petroleum Geologist
George W. Davis, Jr. ..... Petroleum Engineer
P. O. BOX 279 — CASPER, WYOMING

CRUTCHFIELD AND PRUETT
CONSULTING PETROLEUM ENGINEERS
Wilson Tower
CORPUS CHRISTI, TEXAS
John W. Crutchfield — *Harton T. Pruett*

DENTON-SPENCER COMPANY, LTD.
Petroleum Engineers and Geologists
Barron Building — Calgary, Alberta

EARLOUGHER ENGINEERING
Petroleum Consultants - Core Analyses
Specializing in Secondary Recovery
Investigations - Appraisals - Operations
3316 East 21st St.
TULSA 5, OKLAHOMA
Phone: 9-6345

EASTON & SACRE
Consulting Petroleum Engineers
1660 Oak Street
BAKERSFIELD, CALIFORNIA
Phone 2-3934

WARD M. EDINGER
Consulting Petroleum Engineer
Secondary Recovery
Oil and Gas Reserves
Reservoir Analyses
729 Hightower Building
Oklahoma City, Okla. — FO-5-1421

FITTING & JONES
Engineering and Geological Consultants
Ralph U. Fitting, Jr.
J. R. Jones
T. W. Hassell
Petroleum — *Natural Gas*
223 S. Big Spring St. — Box 1637
Phone 4-4451 — Midland, Texas

ROBERT D. FITTING
Petroleum Consultant
Engineering and Geology
MIDLAND, TEXAS
201 West Building — Phone: 4-4922

MICHEL T. HALBOUTY
CONSULTING GEOLOGIST
AND PETROLEUM ENGINEER
Shell Building
Houston 2, Texas — Phone PR-6376

E. W. HOUGH
Emulsion and Paraffin Problems
Box 7547 — University Station
Austin, Texas

JAMES A. LEWIS ENGINEERING, INC.
Petroleum Reservoir Analysts
Dallas, Texas — Evansville, Indiana
Robinson, Illinois
Owensboro, Kentucky — Winchester, Kentucky

MARTIN, WILLIAMS & JUDSON
PETROLEUM CONSULTANTS
Engineering - Geology - Management
131 Central Bldg. — Phone 2-5216
MIDLAND, TEXAS
William H. Martin — R. Ken Williams
Edward H. Judson

WAYNE L. McCANN
Petroleum Engineering and Geology
SHREVEPORT, LOUISIANA
Slattery Building — Phone: 2-8023

M. M. MONTGOMERY
CONSULTING PETROLEUM ENGINEER
Valuations, Drilling, Well Completions,
Production, Workovers,
Property Management
Hapip Bldg. — Williston,
3-4642 — North Dakota

JOHN A. NEWMAN
Reserve Estimates, Property Valuation
Reservoir Analysis
319 Gulf Building — Houston 2, Texas

NOWLAN-DODSON ENGINEERING, INC.
Reservoir Analyses — Water Flood Projects
Natural Gas Engineering
Gas Storage Reservoirs
EVANSVILLE, INDIANA
319 COURT BUILDING — PHONE 5-8154

OILFIELD RESEARCH
Core Analysis — Evaluation
Development of Water Flood Projects
Operation of Water Flood Projects
EVANSVILLE, INDIANA
1907 Division Street
PHONES: 6-5591 (Night, 6-4882 or 6-0608)

PETROLEUM CONSULTANTS
Engineering and Geology
E. O. Bennett — James O. Lewis
D. G. Hawthorn — M. D. Hodges
1552 Esperson Building — Houston 2, Texas

PETROLEUM TECHNOLOGISTS
Production Research — Core Analysis
Secondary Recovery
868 Truckway, Montebello, Calif.
NORRIS JOHNSTON — PArkview 1-5338

KELLER & PETERSON
Petroleum Consultants
Reserve Estimates — *Reservoir Analysis*
Petroleum and Geological Engineering
902 W. T. WAGGONER BLDG.
FORT WORTH, TEXAS
Phone: FOrtune 4340
W. O. Keller — L. F. Peterson

Rates Upon Request

ERNEST K. PARKS
CONSULTING PETROLEUM ENGINEER
Planning, Direction and Examination of Oilfield Operations, Estimates of Oil and Gas Reserves, Oil Property Valuation
306 N. Cliffwood Ave., Los Angeles 49, California
Telephone: Arizona 34832

HARRY H. POWER
PETROLEUM AND VALUATION ENGINEER
Box 1542 University Station
Austin, Texas

E. E. REHN
Consulting Petroleum Geologist
Oil Exploration
Wood Building, 624 Locust Street
EVANSVILLE, INDIANA

R. WAYNE RUSSELL
PETROLEUM CONSULTANT
Geology, Engineering and Management
625 Reserve Loan Life Bldg., Dallas, Tex., Phone ST-3020

JOHN HOWARD SAMUELL
Specializing in Bank Valuations
Geologist and Petroleum Engineer
Compton Building Box 732
Phones 4-4493 and 4-4597, Abilene, Texas

SOL SMITH
CONSULTING ENGINEER
PETROLEUM AND NATURAL GAS
Reserves Deliverability
Oil and Gas Proration
913 BROWN BUILDING
AUSTIN, TEXAS PHONE: 8-9498

WM. H. SPICE, JR.
Consulting Geologist
2101-03 Alamo National Building
SAN ANTONIO 5, TEXAS

SUBSURFACE ENGINEERING COMPANY
Experts in Field Testing, Sampling and Analyzing Reservoirs and Reservoir Fluid for Reservoir Studies.
WRIGHT PETROLEUM LABORATORY
Home Office: Box 1827, Tulsa
Frank Purdum

TRAFFORD & ASSOCIATES
Geological, Petroleum Engineering and Management Consultants

E. Trafford		Phones
R. Pat	Wales Hotel Bldg.	692591
J. B. Newland	10th Floor	61212
K. R. Stout	Calgary, Alberta	61224

East Texas Groups Hold Symposium on Ways To Increase Production in Deep Lime Fields

A symposium on ways to increase production in East Texas deep-lime fields was held May 7 in Tyler. Texas Petroleum Research Committee sponsored the symposium in conjunction with the East Texas AIME Local Section and the East Texas Geological Society.

Morning, afternoon, and evening sessions were featured, with General Ernest O. Thompson of the Railroad Commission of Texas delivering the main address of the evening dinner session. The morning welcoming address was given by William Murray, of the Texas Railroad Commission.

The morning program included papers concerning: "General Subsurface Geology of Deep Lime (Glen Rose) Oil Occurence in Northeast Texas," by R. W. Eaton of P. G. Lake, Inc., Tyler, and John L. Reed, Jr., of W. H. Bryant Interests, Tyler; "Estimate of Primary Recovery from some Typical Glen Rose Fields in Northeast Texas," by G. J. Lotterle of Hundall, Pirtle, and Lotterle, Tyler; "Character of Crudes in the Glen Rose Fields," by Paul Crawford, A&M College of Texas; "Use of High Pressure Gas to Increase Oil Recoveries," by E. R. Brownscombe, Atlantic Refining Co., Dallas; and "Pressure Maintenance by Gas Injection, Opelika Field, Henderson County, Texas," by T. W. Clay, Lone Star Producing Co., Dallas.

Papers presented at the afternoon session were:

"New Hope Field," by Albert Trube, Jr., of Tidewater Associated Oil Co., Tulsa; "Tennessee Colony Field, Anderson County, Texas," by Frank N. Speller, Jr., consultant, Tyler; "Use of Micrologs in East Texas Deep-Lime Fields," by R. T. Wade, Schlumberger; "Advances in Acidizing Deep-Limestone Wells in East Texas," by Paul S. Clinkenbeard, Dowell, Inc.; and "The Banker's Viewpoint," by B. F. Barnett, president of The Citizens National Bank of Tyler.

At the evening session toastmaster Joe Zeppa of Delta Drilling Co., Tyler, presented a talk on the "Operator's Views of Deep Lime Development in East Texas," prior to the talk by General Thompson.

HAVE YOU CHANGED YOUR ADDRESS?

In order that publications and correspondence may reach you promptly, the Petroleum Branch, AIME, should be advised as soon as possible of any change in your address, *preferably a month before the change becomes effective.* For the AIME directory and for the Personals column of the JOURNAL OF PETROLEUM TECHNOLOGY, additional information is desired. The form below is provided for your convenience, and should be sent to Petroleum Branch, AIME, 800 Fidelity Union Bldg., Dallas 1, Tex.

Name_____ Membership No._____

Old Address _____

_____

New Address _____
for
Publications _____

Title or Position Held _____

Address for _____
Directory
Listing _____

List below your former title or company position, nature of your new position, or other information of interest to your associates for publication in the JOURNAL OF PETROLEUM TECHNOLOGY.

_____

_____

_____

One month normally required for change of address.

Let's call a spade--a spade!

NEUTRON–*NEUTRON*
VS
NEUTRON–*GAMMA*
Radioactive Logging

There are but two (2) methods of so-called "Neutron" logging. They are ***NOT*** "alike." PGAC, and only PGAC, uses the Neutron-*Neutron* method which employs a Pure Neutron detector. Commercially used since early 1950, this method alone is ***Simultaneous Radiation Logging*** — done by PGAC exclusively.

THE NEUTRON-*GAMMA* METHOD

All other methods are actually Neutron-Gamma operations because they use — ***NOT a Neutron detector*** — but a Gamma detector intended to measure ***Secondary Gamma Rays*** emitted in the process-of-capture of fast-neutrons from the instrument source as it bombards the various formations in the well.

However, you should remember this scientific fact . . . the gamma counter also detects all "foreign" or unwanted gamma rays already existing in the well. Among such foreign gamma rays are those produced by certain strong and naturally radioactive formations penetrated by the bore-hole. Even more serious are those unwanted gamma rays emitted by the sources which, despite any shielding, affect the counter to some extent. Additional foreign gamma rays are produced by radioactive fluids or compounds sometimes added to the mud or cement.

Obviously, detection and inclusion in the log of such foreign gamma rays erroneously "pads" the actual source reaction intended for measurement alone. True enough, these conditions may or may not exist in your well. But how can you KNOW — or ever BE SURE — that a Neutron-*Gamma* log is not "padded," is truly reflective of your formations ***alone?***

THE NEUTRON-*NEUTRON* METHOD

On the contrary, PGAC's exclusive Slow-Neutron detector measures only the *Pure Neutrons* originally radiated from the logging instrument source — as recorded after they are "slowed down" from bombardment of the formations. Since no "foreign" source of slow-neutron exists in the well, this measuring factor is positive, "unpadded."

Equally important, PGAC's slow-neutron detecter cannot record fast-neutrons from the source, nor gamma rays of any type. It is that simple. Consequently, all risk of error is eliminated when you call for a Neutron-*Neutron* Simultaneous Radiation log . . . done by PGAC ***exclusively!***

FREE . . . VALUABLE PUBLICATION

If you want the complete story, liberally illustrated with actual logs, write today to PGAC, P. O. Box 1435, Houston . . . and ask for your copy of "Radiation Logging And Its Application In The Oil Fields." It is *free* as long as our supply lasts. And there's no obligation — to anyone but yourself to get all the facts. If you're over oil, PGAC always gets more of it — at less cost!

PGAC-546

PGAC PERFORATING GUNS ATLAS CORPORATION

Houston, Texas Telephone: LYnchburg 4161
General Offices: 3915 Tharp St. — Sales Office: Melrose Bldg. — Main Plant: 7730 Scott St.

31 PGAC OFFICES ALWAYS READY TO SERVE YOU . . . CALL THESE TELEPHONE NUMBERS FOR PROMPT SERVICE

TEXAS: Houston, LYnchburg 4161 — Corpus Christi, 3-1324 — Dallas, RAndolph 2943 — Longview, Plaza 9-4486 — Alice, 4-3424 — Mission, 5-1687 Abilene, 2-4172 — Gainesville, 2517 — Odessa, 6-6429 — Beaumont, 2-4263 — Victoria, 1023 — Graham, 1728.
LOUISIANA: Shreveport, 3-1648 — Lake Charles, 4724 — Lafayette, 4-2396. KANSAS: Great Bend, 4306 or 4307. NEW MEXICO: Hobbs, 3-2015.
OKLAHOMA: Oklahoma City, CEntral 2-5342 — Pauls Valley, 1577 — Seminole, 2938 — Healdton, 77 — Ardmore, 857.

AFFILIATE COMPANIES: CANADA—Perforating Guns of Canada, Ltd.; Edmonton, Alberta
GERMANY—Atlas Deutsch-Amerikanische Olfelddienst G. m. b. H.; Kiel

Proposed for Membership, Petroleum Branch

TOTAL AIME membership on Feb. 28, 1954, was 20,445; in addition 1,492 Students Associates were enrolled.

PETROLEUM BRANCH ADMISSIONS COMMITTEE

F. G. Prutzman, Chairman; J. H. Sullivan; F. C. Kelton; C. C. Harter; Virgil Harris; Charles Hudson.

INSTITUTE ADMISSIONS COMMITTEE

O. B. J. Fraser, chairman; R. B. Caples, vice-chairman; F. A. Ayer, A. C. Brinker, R. H. Dickson, Max Gensamer, Ivan A. Given, Fred W. Hanson, T. D. Jones, Sidney Rolle, J. H. Scaff, John T. Sherman, F. T. Sisco, Frank T. Weems, R. L. Ziegfeld.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member, A, Associate Member; S, Student Associate.

California

Bakersfield — Sutton, James Homer (J).
Camarillo — Arthur, James Leland (M).
Glendale — Schoonover, Floyd E. (C/S-A-M).
Huntington Beach — Godbe, Norman Earl (J).
Inglewood — Wiegand, Walter Joseph (A).
Long Beach — Kessler, Walter William (R, C/S-S-M); Richardson, John Osgood (C/S-A-M); Stewart, Floyd La Vern (R, C/S-S-A).
Los Angeles — Barton, Hugh Benjamin (R, C/S-S-M); Norris, William Franklin (A); Steger, James Harry (J).
Redondo Beach — Lilley, Alan Knight (J).
Venice — Ferguson, Hobart Da'e (J).

Colorado

Denver — Brown, Donald Firth, Jr. (J).
Lakewood — Jorgenson, Harold Dudley (J).

Kansas

El Dorado — Allison, Robert Sloan (A).
Ellinwood — Albers, Rollin McCoy (R, J).
Liberal — Phillippe, Jack P. (J).

Kentucky

Owensboro — Ellis, Fred M. (M).

Louisiana

Bunkie — Thomas, Lawrence Eugene (J).
Delhi — Laue, Lamont Charles (J).
New Orleans — Grant, Ralph Gordon (R, M); Rorison, James A., Jr. (M).
Shreveport — Cordell, James Claire (C/S-A-M); Jeffers, Marshall Ambrose (M).

Mississippi

Laurel — Wildbur, Gilbert Leo (M).

Montana

Billings — Parker, John Marchbank (M).
Great Falls — Chamberlain, Virgil R. (R, C/S-J-M).

New Mexico

Hobbs — Heins, Robert W. (R, C/S-S-J).
Roswell — McMinn, John Robert (M).
Tatum — Boone, Daniel E. (J).

New York

Westbury, L. I. — Liss, V. Mitchell (J).

North Dakota

Williston — Nedom, H. Arthur (C/S-J-M).

Oklahoma

Bartlesville — George, Raymond Edward (J); Lahring, Roy Ivan (J).
Drumright — Fly, Jack Paul (R, J).
Duncan — Underwood, David W. (J).
Nowata — La Pointe, Clarence Leslie (M).
Oklahoma City — Dakin, John Dwight (J); Lancaster, Themious Slaten (A); McMahan, Robert Charles (M); Mosley, William Norman (J); Moss, Rycroft Gleason (M).
Okmulgee — Milner, Fred Ewel (A).
Shidler — Knapp, Kenneth Kinch (M).
Tulsa — McNally, H. J. (M); Mitchell, Bryan Earl, Jr. (M); Parrish, David René (J); Renberg, Kenneth (C/S-A-M); Scott, Garner Marion (J); Todd, John Caleb (J).

Pennsylvania

Clairton — Murdy, Richard James (M).
State College — Marsden, Sullivan Samuel, Jr. (A); Newman, Robert Clark (C/S-A-M).

Texas

Abilene — Freese, James Denny (M).
Amarillo — Cox, Arthur Francis (M).
Beeville — Wilshusen, John Hill (J).
Borger — Brammer, Richard Newton (J).
Breckenridge — Crone, Billie L. (R, J).
Daisetta — Melasky, Woodrow Leonard (M).
Dallas — Beck, Edward Charles (J); Gunter, John Raymond, Jr. (A); Pyle, Foster Morris (M); Woerheide, Arthur Edward (M); Zimmerman, John R. (M).
Fort Worth — Montgomery, William Jefferson (C/S-A-M); Tripp, Karl Robert (C/S-A-M).
Garland — Trotman, Joshua Thomas (J).
Graham — Street, William G. (A).
Houston — Boyd, Will Edwin (M); Loper, Prentice Berry (A); McConnell, Leo Vincent (M); Manry, Leon Vernon, Jr. (M); Myers, John Clark (M); Robinson, Leon Haynsworth (J).
Iraan — Morris, Drayton Earl (M).
Kilgore — Kemp, Gore (M).
McAllen — Diehl, Keith Loveall (M).
Midland — Conover, George E. (M); Coone, Malcolm Glen (A); Grove, Dona'd E. (J); Hayes, James C. (J); Johnson, Jesse Pierce (J); McStravick, Peter Robinson (J); Malone, Billy Clayton (J); Stewart, Vernon Roy (J); Stokey, Ernest William (J).
Mineola — Smith, William Clifton (M).
Odessa — Dow, William Andrew (J); Goodnough, Stephen C., Jr. (J); Keil, Byron Lee (R, C/S-S-J).
Pampa — Adcock, Fred Harry, Jr. (J); Daniel, Josiah Martin, Jr. (J); Jones, Robert Eugene (J); Matejowsky, Wil'iam Oswald, Jr. (J); Matlock, James Dver (J); Milliren, Leroy Lester (R, M); Stewart, Haro'd Alvin (J); Stone, James Howard (J); Wallace, Harry Jim (J).
Phillips — Bendler, Jack Charles (J).
San Antonio — Dauchy, Joseph H. (M); Mattei, Joe Braden (J); Rochon, Robert William (M).
Wichita Falls — Auld, Donald K. (A).

Wyoming

Casper — Fusselman, Joseph Landrey (R, C/S-S-M); Pierson, Darrell Stephen (R, C/S-S-J); Tynan, John William (R, C/S-J-M).
Cody — Hegwer, John Scott (J).
Lance Creek — Winn, J. Spencer (J).

Canada

Calgary, Alta. — Hotchkiss, Harley Norman (J); Rousseau, Richard Joseph (J).
Stettler, Alta. — Bohme, Victor Edward (J).

Colombia

Bogota — Colton, George Radcliffe (R, C/S-S-J).

Venezuela

Maracaibo — Salvadore, Andrea Guelfo (J); Walker, Clyde Allen (J). ★★★

Necrology

Date Elected	Name	Date of Death
1940	George M. Dorwart	Dec. 14, 1953
1948	C. O. Denning	Feb. 12, 1954
1903	Howard W. Throckmorton	Feb. 22, 1954
1928	William H. Whittekin	Apr. 10, 1954

Rapid Growth of Branch Continues With 281 New Applications Received

During the first four months of 1954, the Petroleum Branch received 281 applications for membership, including new and reinstatement applications for Junior, Associate, and full Membership.

The four-months total is 20 per cent higher than during the same period of 1953. The table below shows a comparison by months for the two years.

	1953	1954
January	66	52
February	51	55
March	61	66
April	54	108
TOTAL	232	281

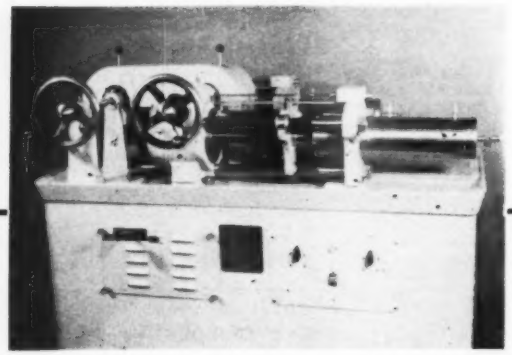
The high figure for April reflects results of the direct mail membership promotion campaign, which began the latter part of March. About 3,000 petroleum engineers and men in related fields have received letters from John R. McMillan, of Fullerton Oil Co., Branch chairman; Joe B. Alford, executive secretary; and G. M. Stearns, of British American Oil Producing Co., advisory editor of the JOURNAL OF PETROLEUM TECHNOLOGY.

Local sections are backing up the campaign by bringing prospective members into their section activities. Many of the applications have come through the efforts of members in areas where new local sections are being formed, in the San Joaquin Valley, Hobbs, N. M., Texas Panhandle, and Hugoton areas.

If applications during the remainder of the year follow the same pattern, about 850 new members will be added to the Petroleum Branch during 1954. Applications in 1953 totaled 691.

It had been estimated earlier that the direct mail campaign and increased efforts of local sections could bring in 1,200 members this year. Several sections are conducting local membership contests in aiming for this goal. The Branch and Institute contests will cover the entire year, rather than selected months as formerly. Suitable prizes will be awarded to the winning local sections.

Membership increase will largely depend on individual members who invite their friends and associates to attend local section meetings and encourage them to apply. The original goal can still be reached. All members are urged to take advantage of this opportunity to interest others in their professional society.



Super Pressure Volumetric and Proportioning Pump

INSTRUMENTS for the Oil Industry

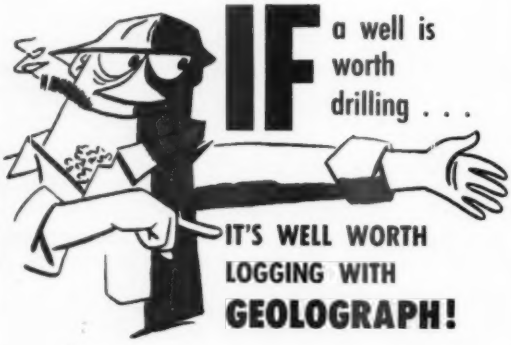
Ruska Instrument Corporation specializes in the development and manufacture of scientific instruments for the oil and mining industries.

- **Reservoir Engineering**
- **Pressure Measurement**
- **Volumetric Pumps**
- **Core Analysis**

Ask for New CATALOG

Ruska Instrument Corporation

4607 MONTROSE BLVD. HOUSTON 6, TEXAS



IF a well is worth drilling . . .

IT'S WELL WORTH LOGGING WITH GEOLOGRAPH!

Shallow or deep . . . your purpose is to make a well . . . and Geolograph can help by giving you a foot by foot record of the formations penetrated! Yes, Geolograph is good insurance for any drilling operation, because you always save when you log as you drill with Geolograph!

GEOLOGRAPH

MECHANICAL WELL LOGGING SERVICE

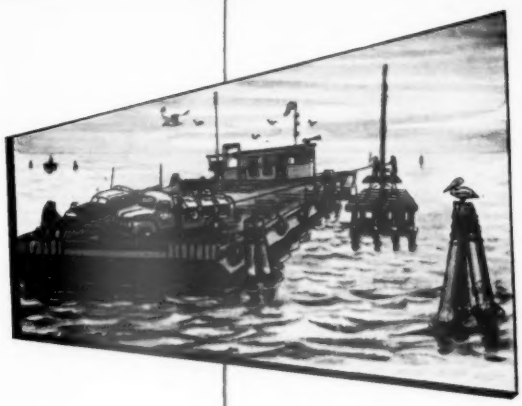
P.O. Box 1291 • Oklahoma City 1, Okla.

Farmington, New Mex. • Liberal, Kan. • Oklahoma City, Okla. • Bakersfield, Cal. Abilene, Houston, Odessa, Lubbock and Wichita Falls, Tex. • Shreveport, and Baton Rouge, La. • Casper, Wyo. • Glendive, Mont. • Sterling, Colo. Edmonton, Alberta, Canada

ADVERTISERS' INDEX

Advance Oil Tool Co.	*
The Aldrich Pump Co.	*
Baash Ross Tool Co.	*
Baker Oil Tools, Inc.	6, 7
Baroid Sales Division	*
B & W, Inc.	49
Byron Jackson Co.	*
The Cavins Co.	*
Clark Bros. Co., Inc.	*
Cooper-Bessemer Corp.	*
Core Laboratories, Inc.	4
Dowell Incorporated	8
Dresser Industries	*
Eastman Oil Well Survey Co.	*
Fluid Packed Pump Co.	*
Geolograph Co.	58
Geological Well Service Co.	*
Guiberson Corporation	3
Halliburton Oil Well Cementing Co.	1, 21
Harbison-Fischer Mfg. Co.	53
Hughes Tool Co.	*
Hycalog Co.	*
Johnston Testers, Inc.	52
Journal of Petroleum Technology	*
Kobe, Inc.	20
Lane-Wells Co.	Fourth Cover
Lufkin Foundry & Machine Co.	40
Magnet Cove Barium Corp.	*
McCullough Tool Co.	19
National Tank Co.	22
Oil Base, Inc.	*
Oil Center Tool Co.	*
Otis Pressure Control, Inc.	Third Cover
Perforating Guns Atlas Corp.	56
Precision Radiation Instruments, Inc.	*
Professional Services	54, 55
Rector Well Equipment	*
Reed Roller Bit Co.	*
Ruska Instrument Corp.	58
Schlumberger Well Surveying Co.	Second Cover
Shaffer Tool Works	34
Shorey Book Store	53
Visco Products Co., Inc.	2
Welex Jet Services, Inc.	*
Western Geophysical Co.	*

*In Previous Issues



Permanent Completions Save Drilling Rig Time, Allow Quick and Low-Cost Testing of Multiple Sands, Reduce Workover Time and Costs, Provide Safer Operations, and Make a Better Producer–

OPC

OTIS

OTIS

PERMANENT

PRESSURE

COMPLETIONS

CONTROL

LICENSED SERVICES

PRESSURE CONTROL SERVICE – EQUIPMENT

OTIS

You get

Maximum

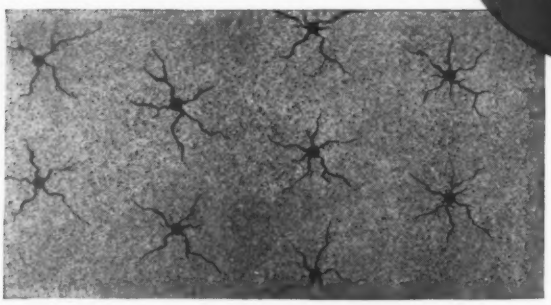
Perforating

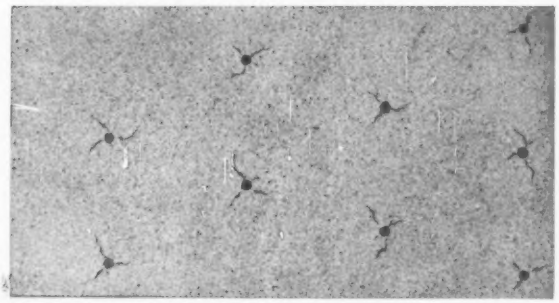
Effect With...

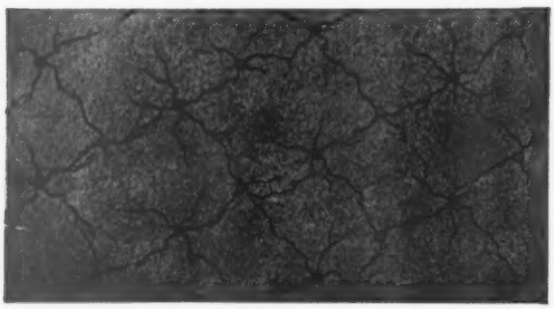
Tomorrow's Tools - Today!

LANE-WELLS COMPANY

COMBINATION Perforating







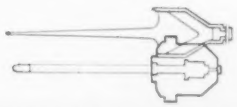
Here's Why:

BULLET PERFORATING

gives good "formation cracking," increasing the drainage area for oil to reach the well.

KONESHOT PERFORATING

gives you deepest penetration, but less formation cracking, and has greater tendency to compact the formation around the perforations.



COMBINATION PERFORATING

Here you shoot first with KONESHOT for your deep penetration — then the bullet perforating fractures the formation and re-opens any KONESHOT cracks which may have been shut off.

***RESULT:* Deepest Penetration Plus Maximum Drainage**

Ask Your Lane-Wells Man

LANE-WELLS *General Offices, Export Office, Plant • 5610 So. Soto St., Los Angeles 58*

LOS ANGELES • HOUSTON • OKLAHOMA CITY • LANE-WELLS CANADIAN CO. IN CANADA • PETRO-TECH SERVICE CO. IN VENEZUELA